PRACTICAL ENERGY AUDIT MANUAL

Mini Steel Plants

Prepared by

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for

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Contents

Contents (Contd.)

List of Tables

List of Figures

List of Appendices

PREFACE

Energy inputs - both electrical and fuel - are an essential part of manufacturing process, and expenditure on these inputs often accounts for a significant share of the manufacturing cost. This is compounded by the fact that the cost of energy is constantly escalating and will continue to rise.

Any saving in energy costs directly adds to the operating profits of the company. It probably requires less effort to improve profits through energy savings than by - reducing labour cost, increasing sales, increasing prices, reducing distribution costs, etc.

The main purpose of an energy audit is to systematically identify practical and feasible opportunities for saving all forms of energy in a plant and realise the benefit of cost reduction. Experience shows that as much as 10-15 percent of energy could be saved without any need of large investments, through energy audits.

The main objective of this manual is to familiarise the plant personnel in the techniques, methodology and approach to in-house energy audits. Since energy conservation is essentially a continuous exercise, it is inevitable that the plant personnel are able to regularly monitor trends in energy consumption and initiate remedial measures to improve energy efficiency.

Section 1 : Introduction

Energy management is a disciplined activity, for the more efficient use of energy without lowering production levels, product quality, safety and environmental standards.

The principle underlying all energy management must be cost effectiveness; energy conservation should and, is restricted to the extent that it can be justified in normal commercial and financial terms. The entire concept, therefore, requires both technical and financial evaluations, along with other considerations such as the human resources, the environmental implications and of course, the ever-present attitude of "no-change" which very often needs a nudge to "change".

Energy management requires a logical and comprehensive management approach. Experience shows that energy savings are only significant and long lasting, when they are achieved as part of a plant energy management programme. A systematic and structured approach is required to identify and realise the full potential of savings that can be achieved, mainly through low-cost measures. The energy management programme can be made "self-financing" - with the savings of the low-cost short term measures being utilised for the implementation of more capital-intensive retrofits. The basis of such a programme has to be a comprehensive and professional energy audit, in order to assess the current consumption pattern and identify potential opportunities to conserve energy, given the existing framework and infrastructure of the industry.

Specific energy consumption-the amount of energy consumed per unit of output – varies widely depending on the product in question, type of manufacturing process, type of fuel consumed, age of equipment, size of the plant, operating practices and even to a certain extent the management philosophy.

However, the savings for a plant, just embarking upon an energy management programme, are 20-30% of current consumption patterns.

Energy conservation thus makes very good business sense!

The mini-steel industry is highly energy-intensive and therefore has been taken up for specific study in this document, as it is highly representative of the core sectors.

1.1 The Steel Scenario

‾he iron and steel industry is the single largest industrial energy consuming ;ector in the world, accounting for nearly 5% of the annual world primary energy lemand (Worrell, 1995). Steel is used in a wide variety of applications, including ıutomotive manufacturing, building construction, industrial equipment, high grade ılloys for oil & gas production rigs and packaging. (UNIDO, 1993).

3teel is an industry with substantial forward linkages. Its importance for a leveloping economy is reinforced by the fact that the per capita consumption of ;teel is often used as one of the indicators of industrialisation and development. ۹s compared to other economies per capita consumption of steel in India at 19 <g is remarkably low, compared to the average of 254 to 578 in advanced ;ountries.

Гhe consumption pattern among major countries during 1993 to 1995 is shown in Гable 1.1. India's share has been only around 3% of world consumption of ıround 630 million tonnes in 1995.

Table 1.1 : World Steel Consumption in Million Tonnes

Country	1993	1994	1995
USA	90.4	98.7	98.0
Japan	75.0	73.2	74.6
EU	93.7	99.5	103.0
China	103.5	95.0	101.0
Latin America	27.0	28.7	30.2
Taiwan	20.9	23.1	25.2
Australia	5.1	5.3	5.3
S Korea	25.2	29.2	30.2
Indonesia	4.3	4.4	4.7
Malaysia	4.8	5.1	5.4
Philippines	2.4	2.6	2.8
Singapore	3.4	3.5	3.6
Thailand	7.7	8.0	8.3
Vietnam	0.8	0.9	1.1
India	16.2	17.6	19.0

From a modest presence in 1947, the steel sector in India has acquired a significant place in the Indian economy a half-century later. India is currently ranked the 10th largest steel producer in the world. The supply of finished steel in India increased from 0.86 million tonnes in 1948 to about 24 million tonnes in 1996 - 97.

The sector, as a whole, accounts for approximately 1% of India's GDP and 6% of the output of the manufacturing sector. Iron and steel contributes 2.4% to the wholesale price index, and is one of the biggest revenue earners for the Indian Railways.

In India, as elsewhere in the world, steel is produced by two main routes: the Integrated Steel Plants (ISPs) and the Mini-Steel Plants (MSPs). The technology adopted for the production of steel in the ISPs is distinctly different from that of the MSPs. In the ISPs, the energy-efficient Basic Oxygen Furnaces (BOF) have replaced the earlier Open-Hearth Furnaces (OHF).

In the BF-BOF route, continuous casting - a technologically advanced method of steel production - has replaced the ingot route in the developed countries and is making significant headway in India.

1.2 Mini-Mills - The Scrap Trap

Most mini-steel plants make steel by melting scrap and sponge iron in an Electric Arc Furnace (EAF), with electric power supplying the heat input. The finished product is an ingot or a concast billet, depending on the technology adopted. Compared to an integrated steel plant, the mini-steel plant requires lesser capital investment, shorter gestation period and has the flexibility to produce different varieties of steel, even in small quantities. The production pattern is shown in Table 1.2.

Table 1.2: Crude Steel Production in India (in million tonnes)

Year	Main Producers	Sec. Producers (EAF/IF)	Total	% Share
1991-92	12.95	4.20	17.15	24.0
1992-93	13.66	4.18	17.84	23.4
1993-94	13.90	3.70	17.60	21.0
1994-95	15.20	4.57	19.77	23.1
1995-96	17.07	5.49	22.56	24.3
1996-97	16.36	7.30	23.69	30.8

EAF steel-making units – popularly known as mini steel plants – existed even before 1947. However, it was in 1959 that the EAF units were formally accorded permission to be set up in the private sector. A chronic shortage of steel and the relatively easy availability of scrap metal led to a significant growth of the mini steel plants in the industrialisation phase of India in the 1970s. According to reliable estimates, a total of 184 EAF units with a total capacity of 10.44 million tonnes annually are in existence. However, the capacity utilisation of the EAF sector continues to be affected by problems of rising input costs, power and obsolete technology, and presently, a general malaise gripping the steel industry world wide, in the face of the economic recession.

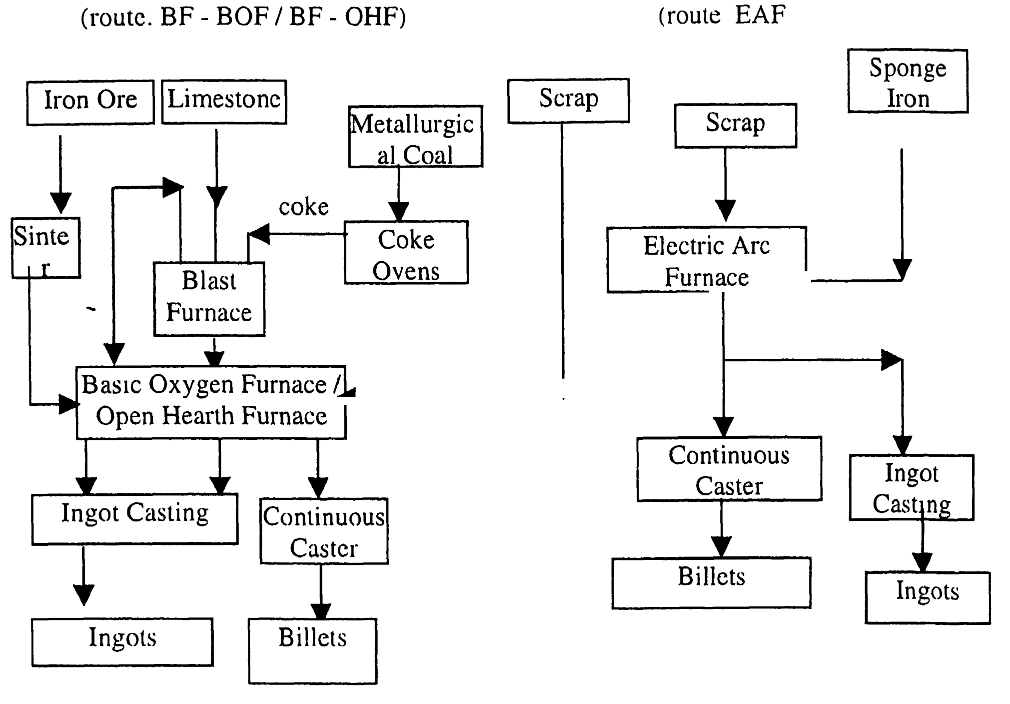
Cheaper imports of steel have also affected the competitiveness of the mini-steel plants, making it imperative for them to reduce the cost of production. This can be achieved only by increasing the production level or reducing input cost. In view of the lack of demand, the former is not a feasible option. Reducing input cost directly implies reducing energy cost or energy conservation. This, therefore, forms the focus of this document.

In the total domestic steel output, mini-steel plants segment contributes about 25-30%. Table 1.3 depicts the contribution of the MSPs to the country's crude steel output.

Table 1.3: Contribution of MSPs to Crude Steel Production

Year	Total crude steel output (Mt.)	Share of mini-steel plants (Mt.)
1989-90	14.3	3.5
1990-91	15.1	3.9
1991-92	15.7	3.4
1992-93	15.8	3.8

Chart 1.1. Flow Diagram of ISPs and MSPs



In 1976-77, the MSPs contributed 13% to the total steel produced in India, but in 1985-86, they increased their share to 30% by 1985-86. In this period, the total steel output registered a compound growth rate of 2.66%, while the MSPs grew by almost 12%. Therefore, it is evident that the mini-steel plants have been able to augment the virtually stagnant ISPs during this period.

Section 2 : Technology / Process Description

The steel making process can be traced back into history as puddled iron and crucible steel making. In mass production stages, these resulted in new technologies such as:

- Acid/Basic Bessemer furnace
- Open Hearth Furnace / Twin Hearth furnace / KORF furnace
- LD Converters / BOF
- EAF / Induction furnace

Mini-steel plants are classified as integrated and non-integrated plants. The former, also called mini mills, consist of a direct reduction (sponge iron) plant, an electric arc furnace shop, continuous casting and rolling mill facilities. Most MSPs in India are non-integrated plants, where scrap is used to charge the EAF with the other processes remaining essentially the same. About 30% of these plants have captive rolling mills.

2.1 Electric Arc Furnace Process

The EAF steel-making method utilises waste resources by using scrap as raw material, while saving energy, since it requires less energy than the blast furnace-converter method to produce a tonne of crude steel.

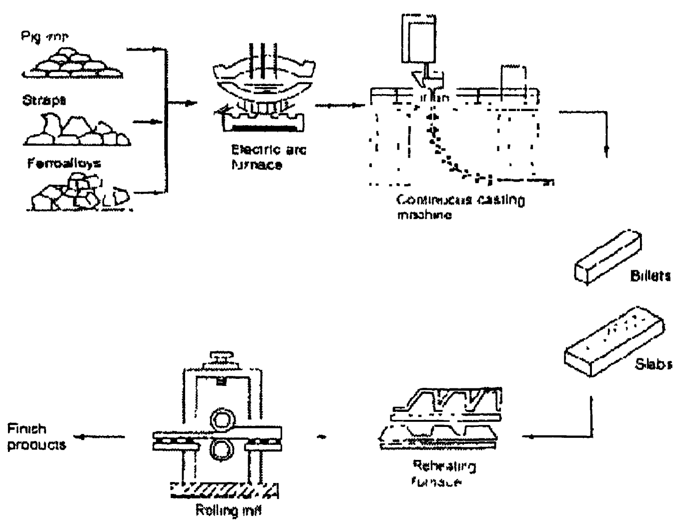


Fig.2.1 : Arc Furnace Steel Making Process

Figure 2.1 shows the EAF steel making process, with continuous casting and rolling mill facilities. A glossary of the terms commonly used in the mini steel plants is placed at Appendix 2. The basic process of steel making in the MSPs comprises the following stages.

Stage I : Melting

The arc furnace, where the melting is accomplished, comprises an outer cylindrical shell lined with refractory bricks to protect it from the high temperature and corrosive nature of the melt. The furnace has a detachable roof lined with refractory bricks. Three carbon electrodes with water-cooled jackets are introduced through an opening in the roof. A three-phase low voltage, high-ampere current, passing through the electrode, serves as the energy source for melting.

The charge, made up of both light and heavy scrap, and in some cases, sponge iron, is dropped into the furnace in stages. The electrodes are lowered to strike an arc between the electrode tip and the scrap material. In this process electrical energy is converted into thermal energy. The melting time of the scrap depends on the composition, shape and weight of the scrap and the power supplied.

Stage II : Refining

When the melting is complete, the refining of molten metal is commenced by the addition of fluxes and de-carborisers. The slag formed during the process is removed from the door at the front of the furnace. The desired chemical composition of the metal is attained by the addition of ferro- alloys and oxygen lancing. The temperature of the melt is raised to the desired tapping temperature.

Stage III : Tapping

After refining, the molten steel is tapped through the furnace spout and cast into ingots or concast billets.

Stage IV : Ladle Refining

The melting efficiency of the electric arc furnace is fairly high, but not the refining efficiency. Also, only about 40% of the available transformer rated power is used during this stage. Therefore, a better practice, already being adopted by many MSPs, is to use the electric arc furnace primarily for melting and use the ladle for

refining. A ladle refining station can be connected to a separate heating source with provisions to add ferro-alloys and fluxes and inject oxygen.

2.2 Technology / Process Description

Mini-steel plants are classified as integrated and non-integrated plants. The former, also called mini mills usually consist of a direct reduction (sponge iron) plant, an electric arc furnace shop, continuous casting and rolling mills facility. Most of the MSPs in the country are in the category of non-integrated plants where scrap is used to charge the EAF, other processes remaining the same. Even among these plants only about 30% have captive rolling mills.

2.3 Raw Material

Steel Scrap, Sponge Iron/ Direct Reduced Iron(DRI)

Scrap constitutes 55 to 60% of the cost of production of billets in MSPs. The availability, quality and price of scrap are major considerations, not only for capacity utilisation, but also for economic operation of the plant. Domestic scrap is generally scarce and of relatively poor quality. This problem has been alleviated by the MSPs by substituting sponge iron.

MSPs use various types of charge mix, depending upon the steel grade to be produced, the availability and price of scrap. Plants located near the ports have a distinct price advantage in using imported scrap and HBI/DRI. Plants located near the ISPs can use steel skull generated by the latter. The plants in the northern region have to depend upon local scrap arisings, in view of the high transportation cost of imported scrap and DRI. The system of scrap collection and availability for different plants is neither systematic nor consistent, varying widely from time to time.

Advantages of DRI

DRI/HBI substitution for steel scrap can be beneficial for MSPs.

1. DRI gives consistently low residual levels for Cu, Sn, Cr, Ni, Mo, as indicated in Table 2. 1.

Table 2.1 : Residual Levels in DRI (All figs. in percentage)

Element	With Shredded Scrap	With 70% DRI
Cu	0.22	0.001 - 0.01
Cr	0.18	0.001 - 0.01
Ni	0.11	0.001 - 0.01
Mo	0.02	0.001 - 0.002
Sn	0.03	0.001 - 0.002

2. Helps foamy slag practices which improves thermal efficiency, decreases refractory and electrode consumption and noise level.
3. Continuous charging with over 30% DRI gives higher productivity.
4. Enables production of high quality steels with close chemistry control and deep desulphurisation.
5. Development of Hot Briquetted Iron (HBI) has been a breakthrough for merchant DR plants, eliminating fire hazards in storage and transportation. It has bulk density of 2.4 - 2.8 t/m^3. It has a low oxidation rate and slow pick up of moisture at 3%.
6. HBI has good thermal and electrical conductivity.

HBI production, pegged at 1.76 million tonnes in 1990, is showing a manifold-increasing trend.

Disadvantages of using DRI

1. The major disadvantage is in higher slag volume due to large gangue in the burden and consequential higher electricity consumption.
2. Electricity consumption is also affected due to degree of metallisation, metallic and total Fe, and basicity of gangue.

By now, sponge iron has been recognised as an alternate raw material to scrap by the MSPs. Apart from augmenting scrap, there are positive advantages of using sponge iron in the charge mix:

1. Stabilisation of scrap price
2. Better consistency in chemical composition of charge, compared to scrap, thus facilitating stabilised operation of the furnace.
3. Ease of handling and transporting sponge iron due to uniformity in size

4. Ease in furnace operation with continuous feeding of sponge iron.

There are however some disadvantages in using more sponge iron such as, higher refractory wear, higher power consumption, lower charge to liquid steel yield. Use of HBI can be marginally more advantageous, compared to sponge iron, in terms of consistency in hot metal quality and smoother operation of furnaces. But, HBI may need to be imported, increasing its price, with its additional power consumption.

All the above factors need to be evaluated in conjunction, while taking a decision on the raw materials, by the individual units.

At the outset, in order to generate maximum energy saving, it is essential to examine the metallurgical conditions, density and cleanliness of ferrous scrap charged into an EAF. In a typical solid to liquid phase, transformation heat and superheating of molten steel account for around 75 and 25% respectively, of the energy requirement for melting scrap. Therefore, reducing the amount of energy required for melting scrap can significantly reduce electricity cost for EAF operation.

The scrap handling system should be organised to obtain a high degree of uniformity in both analysis and size of the scrap burden, by subjecting all incoming scrap to stringent quality control norms and determining the composition precisely. The layout of the scrap yard should provide a continuous flow system with minimum bucket movements. Loading instructions should be based on the projected production programmes and adhered to keep the steel composition variance within a narrow range and ensure standard conditions for subsequent operations, such as scrap pre-heating and alloy addition.

In conjunction with oxy-fuel burners located at furnace sidewalls, light scrap such as fragmented scrap and turnings with greater surface area per tonne, can be heated more efficiently than heavy scrap with less specific surface area. However, if very light scrap is used, there can be a risk of excessive oxidation leading to poor melting yield. In addition, its low density entails more back-charging to load the furnace, resulting in lower productivity. Power input in the early stage of melting light scrap should be low to prevent electrodes from boring through the charge and damaging the hearth refractories. Light scrap also tends to weld together and stick to the furnace wall, requiring additional time for complete melting.

With an all-bucket charging practice, it is desirable to limit the number of buckets per heat to two by using high-density scrap such as rolling mill crops. But, this can lead to poor furnace fill ratios and high radiation heat losses from water-cooled sidewalls and roof panels. Operational results have demonstrated substantial energy savings with 30% heavy scrap, and no benefits by further increasing this percentage.

Improving lifting hydraulics could shorten the time required to open the furnace roof from five minutes, while reducing heat losses per charge bucket from 10 to 6 kWh/t. Similar tests show that, by slashing the third bucket charging, melting time could be cut by up to ten minutes with a gain of 10 kWh/t. Higher material compactness in a bucket containing up to 35% of fragmented scrap could raise furnace productivity by nearly 10%.

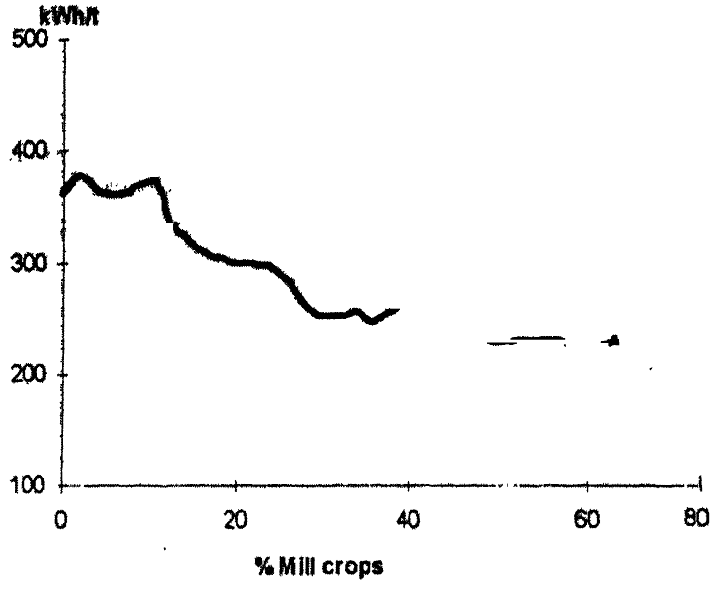


Fig.2.2: Effect of Scrap density (1st basket) on Power Consumption of EAF

One adverse effect of using ferrous scrap is the presence of residuals such as copper and tin - picked up during steelmaking - which may effectively destroy any cost advantage of the arc furnace route. The solution to this lies in judicious scrap selection and dilution with pure iron sources. In order to control feed stock quality, mini-steel-makers are resorting to backward integration into scrap selection, preparation, screening and processing.

The hike in costs due to scrap selection and upgrading could be offset by energy saving, yield gains and metal recovery. Industrial experience suggests a 9 - 17 kWh/t increase in energy consumption, when melting ferrous burden containing 1% gangue or lime, moisture or iron oxides such as Fe_2O_3. This is illustrated in Table 2.2.

Table 2.2: Effect of Feedstock Quality on Energy Consumption of EAF

Contaminant	Percentage	Energy Increase - kWh/t
Acid gangue	1	9.5
Moisture	1	17.0
Iron Oxide	1	14.3

Dilution with pure iron sources, such as Direct Reduced Iron (DRI), increases electrode consumption. Operating the EAF with completely DRI, instead of ferrous scrap, would raise energy requirement by 155 - 240 kWh/t, by way of lower yield and decline in productivity.

Fig. 2.3 shows the Georgetown Steel trend of increase in power consumption by 77 kWh/t, with 50% Midrex pellets in the burden.

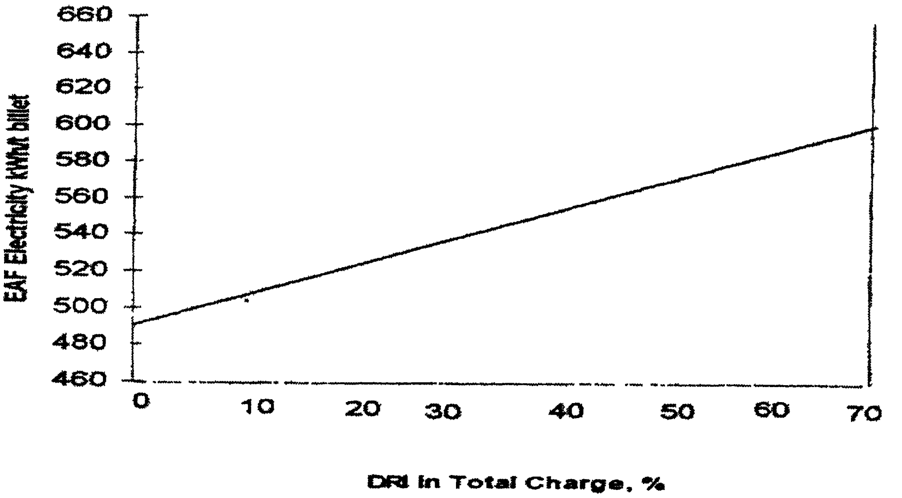


Fig.2.3 : Impact of DRI on EAF Energy Consumption

Since it is uniform in size and shape, DRI can be continuously fed into the EAF from a fifth hole in the roof. At low levels of dilution, continuous charging of DRI results in several improvements in melting, with consequent reduction in power requirement. Keeping the dilution to 10-30% has been known to conserve 3% power and reduce tap-to-tap time by 5-10%.

The potential for energy reduction can increase by process coupling a direct reduction (DR) unit with an arc furnace, to fully utilise the sensible heat retained by the hot DRI discharged from the DR unit. Mexico's Hyisa S.A. de C.V. has an interesting aspect of providing 70% DRI burden charging at 650°C for a 19% improvement in energy consumption and a 20 minute reduction in tap-to-tap time, as shown in Fig. 2.4, vis-à-vis a 100% cold DRI burden. However attractive this coupled process is, it is rarely practised in EAFs other than green-field sites.

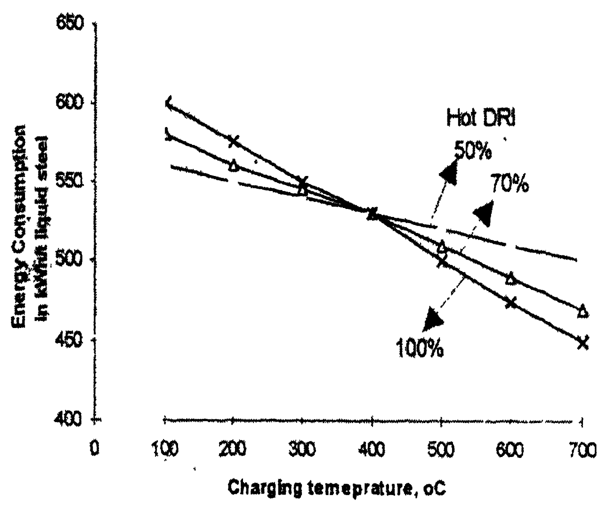


Fig 2.4 : Effect of Temperature of Hot DRI on EAF Electricity Use

Ferro-alloys and De-oxidisers

Variations in use of ferro-alloys from plant to plant occur due to charge mix composition, percentage of alloying elements in ferro-alloys and degree of recovery, which depends upon the melting practice and subsequent refining facility.

Fluxes and Other Additions

Calcined lime/limestone is used for steel refining and fluorspar for increasing slag fluidity. A plant with a limekiln can use calcined lime, which is preferred to limestone, because lime reduces power consumption.

Electrodes

The three electrodes are made of graphite rods, supported on an electrode arc. The arcs should be rigid enough to bear the mechanical resonance frequencies and other dynamic forces acting upon the arm. The consumption rate of electrodes depends upon various factors, such as the quality of the electrode, material and melting practices.

Electricity

Electric energy, used for melting, is supplied by the furnace transformer, normally rated at 350 to 450 kVA per tonne. The three electrodes are connected across the secondary of the transformer with an on-load variable-voltage tap changer. The basic requirements of the electrical system are :

- Low electrode current
- Arc stability
- Over current protection
- Insulation of furnace from supply during charging and metal tapping.

Oxygen

Oxygen could be used to assist in melting and speed up the refining operation. It can be injected through a lance during melting. Oxygen reacts with the steel, enhancing the melting rate, thus reducing melting time, increasing furnace productivity and reducing specific consumption of electrical energy.

2.4 Plant Production Capacity

For a certain size of the electric arc furnace, the production capacity of the plant, normally designated in terms of tonnes of crude steel per annum, depends upon the furnace availability, heat time, yield and product mix.

Furnace Availability

Electric arc furnaces are designed to work continuously, throughout the year, on a three-shift basis. The furnace availability depends upon the scheduled down

time on account of preventive maintenance, refractory repairs in between heats and relining, mechanical and electrical breakdowns. Power cuts and interruptions also cause downtime.

Heat Time

The number of heats per day depends upon the capacity rating of the furnace transformer, charge mix, steel grade produced, oxygen usage during melting or refining, level of automation and mechanisation of operation.

Yield

This is the amount of liquid steel/ingot/billets that can be produced from one tonne of ferrous charge material. The yield can vary considerably depending on the grade of scrap and contaminants included. Clean segregated scrap has a better yield factor. The yield also varies with the type of casting i.e., ingots or billets.

Product Mix

This refers to the different types of steel produced in varying quantities, which would have a direct bearing on the capacity of the mill. More difficult profiles and sections would undoubtedly reduce the production capacity.

Section 3 : Industry Profile and Energy Consumption Pattern

The arc furnace route of producing steel, which, once upon a time, offered lower capital investment and a low gestation period, was exploited with the active encouragement and support of the government of India. This resulted in a spurt in the growth of such mini-steel plants in the country, with attractive incentives for the investor also.

Over the years, however, the mini-steel plant scenario changed drastically. The low utilisation of the arc furnace capacity and poor performance indices resulted in loss of production economy. Most of the mini-steel plants lacked the technical know-how, energy resources and manpower to run the furnaces.

Most small units in the industry turned sick, with the exception of a few that had a sound technical base. The development and structure of the mini-steel plants has also been influenced by changes in demand from industrial consumers. A typical case is the gradual replacement of mild steel by alloy steels in many industrial applications.

3.1 Structure of the MSPs

There are over 184 MSPs, with a total installed capacity of 10.5 million tonnes of crude steel. Roughly, the northern region has 40% of these MSPs, while the western region has 30%, the balance being divided between the south and east of the country. The capacity of the EAF in India ranges from 5 to 50 tonnes as illustrated in Table 3.1.

Table 3.1 : Size classification of electric arc furnaces

Size in Tonnes	Percentage
Less than 10	38.0
10 - 17	51.0
21 - 35	8.5
40 - 50	2.5

In recent times, there has been a disturbing trend of plants closing down due to non-viable economic parameters. Even amongst those units still in operation, the average capacity utilisation has been below 60%.

Reasons for Closure of Mini Steel Plants

- Power tariffs and shut downs imposed by State Electricity Boards
- Increase in cost of imported raw material, particularly scrap
- Shortage of scrap
- Uneconomical furnace sizes, technological obsolescence
- Higher specific consumption of input, materials and energy
- Unfavourable market conditions
- Inconsistency in demand for steel
- Dumping of imported steel, making for tough competition by way of quality and price.

3.2 State of Technology

As in most other industries, the techno-economic parameters of Indian steel plants, specific energy consumption, consumption of raw materials and pollution control norms, continue to lag the developed countries.

In the past, the Indian MSPs were mostly scrap-based EAFs, mini blast furnaces and DRI-based EAFs. Despite the use of inferior technology, the cost of steel production in India was low, due to the availability of low cost primary raw materials and cheap labour.

3.3 Energy Intensity of MSPs

In MSPs, the major energy resource is electricity. The consumption in Indian plants is around 600-900 kWh/t crude steel, compared to 400 kWh/t or even less in the better operating plants abroad. Energy cost constitutes 15 - 20% of production costs in the MSPs, and in fact in the ISPs too.

Electrical energy is used for the arc furnaces for melting and refining steel, electrical magnets, EOT cranes for handling and charging scrap, concast machines, and for auxiliaries such as the pump house, cooling towers and air compressors. Fuel oil or gaseous fuel is used for ladle and tundish preheating. The energy break up of an arc furnace is shown in Table 3.2.

Table 3.2 : Major energy consuming areas in an arc furnace

Section	% Energy distribution
Melting	60 %
Refining & Tapping	31 %
Auxiliaries	9 %
Total	100 %

3.4 Specific Energy Consumption Norms

Technological Parameters

- Utilisation of Ultra High Power (UHP) furnace
- Oxygen lancing
- Water cooled panels
- Computerisation of power feeding
- Utilisation of ladle refining furnace
- Use of cold tundish practice

Major factors affecting specific energy consumption:

- Plant layout and systems engineering
- Design capacity of the plant and the capacity utilisation
- Rate of melting
- Raw material composition
- Quality of raw material used
- Quality of power available
- Type of final product
- Type of control & monitoring mechanism
- Adoption of energy efficient technologies in

The types of energy consumed by the equipment are already discussed. Two specific cases of the logic of deriving energy consumption norms are given below.

Case-1 : Metal is melted in the EAF and refined in ladle refining furnace

The characteristic features of a 30-MT arc furnace, operating at 500 kWh/MT of liquid metal, are:

- Computerised power feeding to the furnace
- Oxygen consumption of 25 Nm^3/MT of liquid Metal
- Electrode consumption of 4.0 kg/MT of liquid metal
- Burnt lime consumption of 50 kg/MT of liquid metal
- Coke consumption of 8 - 10 kg/MT of liquid metal
- Melting time of 80-90 minutes/batch
- Holding time of 20 - 30 minutes/batch
- Tapping time of 2 - 3 minutes / batch
- 10% more production than rating of arc furnace
- Molten metal tapping temperature of 1680°C

The features of the arc furnace at 525 kWh/MT, when compared to 500 kWh/MT operation, are manual control of power feed to furnace, greater melting time and variation in raw material consumption. Similarly, the norms for a 15-MT arc furnace and a 45-MT UHP arc furnace have been developed as shown in Table 3.3.

Table 3.3 : Specific Electrical Energy Consumption (kWh/MT of liquid metal)

Area	Sp. Energy Consumption
15-MT arc furnace (melting only)	580 – 590
45-MT UHP arc furnace (melting only)	470 - 480
30-MT arc furnace (melting only)	500 - 525
Arc furnace auxiliaries (without scrap preheating)	45 - 50

The last value is dependent on the following aspects

- Production at arc furnace
- Type of pollution control equipment such as bag filters and fumes extraction blower
- Pumps and other minor energy consumers such as cranes.

Typically, the energy consumption in the furnace auxiliaries are in the arc furnace hydraulic system, cooling tower pumps and fans, compressors, EOT cranes, lighting and the ladle preheating burners. The break up of specific energy consumption in an arc furnace auxiliaries is shown in Table 3.4.

Table 3.4 : Break-up of SEC at Arc Furnace Auxiliaries

Item	SEC
Cooling water pumps & cooling tower fans	28.0 - 29.0
Fumes extraction blower	9.5 - 10.0
Hydraulic system, lighting, cranes etc.,	7.5 - 11.0
Total	45.0 - 50.0

Ladle refining furnace

The molten metal from the arc furnace is refined in a ladle-refining furnace. The characteristic features of ladle refining furnace operating with 75 kWh/MT of liquid metal are as follows:

- Ladle refining furnace treatment time 45-50 minutes
- Continuous monitoring of ladle refining furnace treatment time
- Electrode consumption of 0.6 to 0.65 kg/ton
- Practice of ladle preheating
- Practice of ladle insulation
- Manual monitoring of power fed to the furnace
- Steam ejector based vacuum degassing. (Short pumping time)

The characteristic features of ladle refining furnace operation with 77 kWh/MT of liquid metal when compared to 75 kWh/MT are more refining time, more holding time of the furnace and variation in raw material consumption. These norms are shown in Table 3.5.

Table 3.5 : Specific Electrical Energy Consumption (kWh/MT liquid metal)

Area	Sp. Energy Consumption
Ladle furnace (refining only)	75 - 77
Ladle Furnace Auxiliaries	20 - 22

Case 2: Metal is melted and refined in EAF

This is generally practised in smaller plants with a capacity of less than 15 MT per batch.

Specific electrical energy consumption	KWh/MT of liquid metal	670 - 680

The characteristic features of the arc furnace operating at 670 kWh/MT are:

- Oxygen consumption : 15 Nm^3/MT
- Electrode consumption : 3.5 kg/MT
- Coke consumption : 20 kg/MT
- Melting time : 140 minutes / batch
- Tapping time : 12 minutes / batch
- Molten metal temperature : 1650°C
- 10% more production than rating of arc furnace
- Batch-wise and daily monitoring of power fed to the furnace.

Ladle Preheating

Specific thermal consumption	Lts/MT of liquid metal	3.5

The features that lead to specific energy consumption of 3.5 Lts/MT are:

- Utilisation of slide gate for pouring molten metal from ladle to tundish
- Covering ladle with insulated hood during non-operating period between two tappings. (Some plants preheat ladle once every 3-4 tappings)
- Horizontal preheating of ladle instead of vertical reducing energy consumption at ladle.

Tundish Preheating

Specific thermal consumption	Lts/MT of liquid metal	Nil

This is applicable for cold tundish operation only. By adopting good insulation practices, the thermal energy consumption at tundish can be totally avoided. The practice of cold tundish leads to some additional benefits such as:

- Totally avoiding oxygen lancing for residual metal cleaning
- Better temperature control of molten metal

Preheating tundish is a prevalent practice, with norms ranging from 0.8 - 1.0 Lt/MT of liquid metal. The existing hot tundish can be converted to cold tundish.

3.5 Growth Potential

A study by Crisil finds a strong correlation between steel consumption and GDP, which is expected to grow at an average rate of 6% till the end of the century. A

study by Department of Steel, Ministry of Mines & Steel indicates a shortage of 2.3 million tonnes of steel during the year 1999-2000.

This clearly indicates that the requirement and consumption of steel in India will go up drastically in the future, forecasting a good potential for the growth of the industry to match the demand and availability.

Various measures to achieve energy conservation are elaborated in the next section, while Table 3.6 illustrates the potential opportunities to save on the energy bill.

Table 3.6 : Energy consumption pattern and energy saving potential

Description	**Number of units**	**Annual Energy Bill Rs. Crores**	**Savings**		**Investment required Rs. Crores**
			Rs. Crores	**% of energy bill**	
Ministeel (EAF only)	> 200	700	55	7.5	100
Re-rolling mills	1100	700	70	10.0	100
Overall		1400	125	8.9	200

Section 4 - Energy Conservation Opportunities

The theoretical electrical energy requirement for melting one tonne of steel from room temperature to a temperature of 1500°C is 342 kWh, but the actual power consumption varies from 400 to 525 kWh per tonne. The electrical energy in the refining stage is around 200 to 300-kWh/ tonne liquid metal for mild steel.

Apart from melting and refining, energy is required for the auxiliaries, such as water cooling in arc furnaces and the con-cast machines, scrap handling and charging. On an average, the total electrical energy required per tonne of finished ingot/billet, including the auxiliary load, is 600 to 700 kWh/tonne.

A few opportunities for conservation of energy are outlined below.

4.1 Ladle Preheating

In steel making, a certain amount of super-heating of steel is necessary to compensate for the heat losses in pouring to ensure that the liquid metal is at the right temperature for ingot teeming or continuous casting. The ladle has to transport the molten steel from the melting furnace to the casting bay. The molten steel remains in contact with the ladle for a considerable period of time.

Ladle preheating is necessary to raise the temperature of the refractory lining to around 700-1000°C. This is required to:

- Avoid explosions when molten steel is poured into the newly lined ladle.
- Remove any moisture in the lining that could create gassing of the metal.
- Eliminate undue chilling of the liquid steel during casting, which could lead to excessive skull formation, thus reducing yield.
- Prevent solidification of the molten steel in the ladle itself.
- Reduce thermal shock in the lining when steel is poured.

The benefits of efficient ladle preheating are:

- Reduction in electricity consumption in EAF
- Increased lining life of the ladle
- More uniform heating of metal.

However, ladle and tundish preheating requires about 6 - 21 litres more of furnace oil. Other types of energy inputs are petroleum coke, graphite electrode, and oxygen.

4.2 Plant Operation Specific Factors

Various operational factors influence specific energy consumption such as:

- Arc furnace and furnace transformer capacity
- Composition of charge mix and quality of scrap
- Capacity utilisation
- Grade of steel produced
- Method of casting adopted (ingot / concast)
- Metallic yield
- Voltage fluctuation and power supply interruptions

Steel production through the EAF route is energy intensive due to the application of old technology, inefficient equipment and material losses in the process. Some measures to improve energy efficiency include:

- UHP Process
- Oxy - Fuel injection
- DC Arc Furnaces
- Efficient ladle preheating
- New furnace types

4.3 Optimal Utilisation of Heat Energy from Steel Melting in an Arc Furnace

Medium Term

Melting of steel in the arc furnace method also involves removal of undesirable components such as phosphorous, sulphur, hydrogen and oxygen from the steel, by various chemical reactions such as de-carburisation, de-phosphorisation, de-sulphurisation and de-oxidation. These reactions also impart the required physical and mechanical properties by adjusting the contents of the major components.

In order to achieve optimal utilisation of heat energy, it is essential to perform the whole process as quickly as possible, since the reactions may proceed irreversibly if the material remains under melting conditions for a long time. Some methods used to accelerate the melting process include:

- Use of oil burner for auxiliary melting of material in the furnace
- Use of lance pipe to stop supply of oxygen
- Oxygen blowing into the metal bath
- Use of heavy weights to compress bulky feed material in the furnace

4.4 Energy Efficiency Improvement - Areas for Attention

Table 4.1 reveals a comparison of the major differences between typical mini-steel plants in India and best operating plants abroad.

Table 4.1 : Comparison of Indian and Foreign Plants

Parameter	Indian Plant	Foreign Plant
Furnace size	Small (70% below 15 t)	Large 80 - 300 t
Furnace transformer rating MVA/t	Low & medium power operation 0.3 to 0.5	High & Ultra, High Power operation 0.7 to 1.0
Heat time, minute	200;(approx)	60 or even less
Activity, t/h	1-12	More than 30
Power consumption kWh/t	600 – 900	400 or even less
Electrode consumption kg/t-	3	1.2 – 2
Oxygen usage Nm^3/t	Not intensified consumption< 1 0	More than 20
Furnace refractory lining	Limited	Excellent
Process technology & development	Mostly imparted	Upgraded continuously
Automation	Minimal	Excellent

Energy Savings in Process Areas

Since the energy consumed in MSPs largely depends on the efficiency of the arc furnace operation, an energy balance of the EAF would be a clear indicator of the energy use, losses and gains in the process.

However, before preparing the energy balance, a material balance for the furnace needs to be established. Typical inputs for the balance include the charge, graphite electrodes, limestone or calcined lime, coke, oxygen and alloying constituents, while molten metal, scrap and exhaust gases constitute typical outputs. This is illustrated in Table 4.2.

Table 4.2 : Energy balance for producing one tonne of steel in a typical EAF

Break-up of unit energy input	Percentage
Electrical power	0.76
Exothermic reaction like de-carburisation etc.,	0.23
Graphite electrode oxidation	0.04
Total	1.00

Note: Oxy-fuel burners also supply energy though not shown in this chart

Elimination of delays and obtaining maximum output from the EAF would ensure energy economy in the melting stage. The three most important parameters which affect the productivity of the arc furnace are tap to tap time (i.e., time taken to charge the EAF, melt the scrap, refine the scrap and tap molten metal) furnace availability and yield. It is essential that the entire operation of the furnace, furnace preparation and repairs, charging, melting, refining and tapping all be well planned.

Charging : The selection of charge should be carefully done to suit the meltdown operations. In the case of alloy steel production, it should result in a melt down bath analysis, which is close to the customer's product specifications.

Better Charging Practice

Opera-tional

Bulk density and the scrap size have a close relation with the specific energy consumption. The initial charges should always be of maximum density to achieve the required tonnage with minimum number of recharges after the initial meltdown starts. Each opening of the furnace is expected to increase energy consumption by 8 to 10 kWh/t of material melted.

A charge made up entirely of heavy scrap is also not desirable, since it does not permit shielding of roof and walls during the melt down period to the same extent as a mixed charge of greater volume, and is likely to reduce refractory life.

Scrap Segregation

Opera-tional

It is necessary to segregate the available scrap into stock piles of specified grades to ensure that the desired mix is prepared for charging into the furnace. This implies close adherence to a scrap segregation programme consistent with the variation in quality of the material available.

Melt Down Practice

Opera-
tional

An ideal melt down practice should achieve heating of charge as evenly as possible from the centre to all other exposed areas, with emphasis on a few aspects.

- The electrode should be lowered as close as possible to the charge by push button operation to reduce the time required to strike the initial arc.
- A suitable voltage level should be selected to inject enough energy into the arc to allow the electrodes to bore down into the charge until they approach the heavy scrap at the furnace bottom. This permits greatest absorption of the arc energy and promotes economic use of power-
- Rationalisation of metal melt down practice reduces specific energy consumption - second or third time scrap charging is normally decided based on experience of the melters. It is desirable that, based on the materials, the plant establishes a relationship for power consumption vs time for different grades of scrap, and accordingly, evaluates the time for charging a second or third time.

Tapping Temperature Regulation

Opera-
tional

Normally liquid metal temperature is kept at a higher margin of 150-200°C over the tapping temperature to accommodate the drop in temperature in the tapping process. In operations based on manual control, there is a tendency to keep the temperature higher than standard/optimum temperature.

Every 10°C increase in tapping temperature can increase specific electrical energy consumption by about 19 kWh (at 30% furnace efficiency during refining). The higher degree of efficiency in superheating has other adverse effects on the quality of steel and consumption of electrode and refractories. It is suggested that standards for tapping should be set based on a study of temperature drops for different steel grades.

Furnace Lid and Charging

Opera-
tional

The furnace lid should be opened every time the furnace is charged. Enormous heat losses occur from the exposed molten metal and any delay in charging low bulk density scrap or failure to re-close the furnace lid results in decreased furnace efficiency.

Capacity Utilisation Factor

Opera-tional

The specific energy consumption decreases with increase in capacity utilisation. Under-utilisation of the furnace may be the result of poor availability, due to high maintenance downtime, process delays and factors external to the process, such as like power interruptions.

Typical internal delays that affect specific energy consumption and are mostly controllable are:

a. Delays in crane service or in scrap delivery, shut downs for power inadequacy and mechanical failures.

b. Scrap charge of incorrect chemical analysis may affect the furnace schedule and result in melting to a different specification than the analysis desired (improper segregation, charge planning)

c. Breakage of electrode due to heavy pieces of scrap at the sides of the furnace falling during melt down, large concentration of charge material such as limestone while the electrode drive continues to exert downward force as long as current in that leg of the circuit is low.

d. Errors in the selection of power input levels may result in slow melting rate and damage the furnace lining in roof.

Efficient Use of Fuel Oil

Opera-tional

Saving in oil consumption can be achieved by improving operational practices such as pre-heating, reducing excess air levels and reducing excess gap between ladle and roof. Other measures to improve fuel efficiency include:

- Installation of slide gate system on ladies instead of conventional/stopper rod assemblies requiring replacement after every heat, which reduces fuel and time for ladle pre-heating .

- Utilising garnex board with back-lining of ramming mass instead of high alumina siliminite bricks deployed in the conventional system or concast machine. This measure could eliminate the requirement of furnace oil or LDO for tundish pre-heating.

Economies of Scale 1 Size EAF

-ong Term

The specific energy consumption decreases with increase in furnace size due to the accompanying decrease in surface area to volume ratio and related decrease in specific heat losses. The sizes of arc furnaces operated in India are small compared to those prevalent in developed countries. Indian furnace sizes range from 5 t to 50 t with an average of 12t, compared to sizes more than 150t in the developed regions.

The advantages of larger furnaces are lower investment and fixed operating costs cost per tonne output, marginally lower power and electrode consumption per tonne output. Moreover, furnaces of more than 25t capacity could provide economy by measures like scrap pre-heaters, oxy-fuel burners, UHP transformers and greater degree of automation in operations.

In recent developments, the heating capacity of the ladle furnace has been ingeniously employed to produce several grades of steel with smaller lot sizes out of a single EAF heat, with consequential energy savings. Instead of using a 20t EAF twice, a single 30t heat can produce two heat sizes of different steel grades. This is also illustrated in Table 4.3. It starts with a 35t initial charge and proceeds with the standard melting practice, After slag-off, the first and second batch of heats (about 15t each) are tapped successively into the two ladle furnaces. After the first tapping, a further 2t of scrap can be added via the de-slagging door to increase the total heat size to a maximum of 37t without any delay. Within seven minutes, the second heat is ready to tap. This practice is reported to save 20% energy and reduce 15% of processing (excluding labour) by elimination of smaller furnace operation.

Table - 4.3: Change of Energy Parameters and Costs by Operating a 30t EAF to Produce Two Heat Sizes Instead of Operating at 20t Twice.

Parameter	Consumer	20t (operated twice)	30t (operated once)
Electricity (kWh/t)	EAF+Auxiliaries	610 (100)	490 (80)
	EAF	525 (100)	395 (75)
Electrode consumption (kg/t)	EAF+Auxiliaries	5.35 (100)	4.20 (80)
	EAF	4.70 (100)	3.35 (70)
Refractory Cost (%)	EAF+Auxiliaries	(100)	(75)
	EAF	(100)	(45)
Total		(100)	(85)

4.5 Operation of Arc Furnaces

Opera-tional

In order to save energy in the actual operation, it is imperative to:

- Reduce the operating time
- Raise the resistance welding time in order to eliminate wasteful power consumption. Consequently, use of excessively bulky materials should be avoided. If unavoidable, they should be pressed and massed together
- Effectively use oxygen blow to quickly raise the temperature to over 1,600°C. The use of a poker is desirable
- Secure operation speed to ensure close co-ordination between the crane and other operators, in order to reduce the waiting time for crane availability
- Install high-powered transformers and carry out rapid dissolution

The melting rate depends largely on the transformer capacity as shown in Table 4.4.

Table 4.4 : Production at different electric power levels (70-tonne furnace)

	Melting time [min]	Theoretical production rate (l/m)	Ratio of efficiency (%)
RP	159	100	100
HP	105	150	150
UHP	70	230	230

4.6 Feed Material

Short Term

The type of feed material used depends on the product. Machine chips, pressed steel scraps, light steel scraps and steel casting scraps are generally used for producing bars and sections, while steel casting scraps, light steel scraps, machine chip scraps and steel casting scraps are common raw materials for steel castings.

In the former, feed materials are bulky and cannot be fed in one step, requiring three or more steps. It is essential to prevent non-ferrous metals such as copper, aluminium and non-metallic substances such as rust and oil from entering the feed material. Usually, feeding is done by opening the canopy and using a charging basket in several steps.

In the first step, machine chips are laid on the floor of the furnace. Next, limestone, light steel scraps, returned scraps, pressed steel plate scraps, light steel scraps and machine chips are fed in this order. Subsequently, pressed steel scraps, light steel scraps and machine chips are fed onto the metal bath at the bottom. In the third process, returned scraps, steel casting scraps, pressed steel plate scraps, light steel scraps and machine chips, carried in a charging basket are fed in this order from the top of the furnace onto the metal bath.

It should be ensured that bulky materials are at the bottom while lighter ones are at the top. This permits the efficient use of electric power, while preventing damage to the rod electrodes.

A bypass may be provided between the dust collector and the arc furnace, with a charging basket placed there for pre-heating in waste gas. This can reduce the power consumption by 20-50 kWh/t.

4.7 Furnace Cycle

The furnace charge cycle for a typical furnace with a capacity of eight tonnes and a charge of 10 tonnes is illustrated.

Melting Period

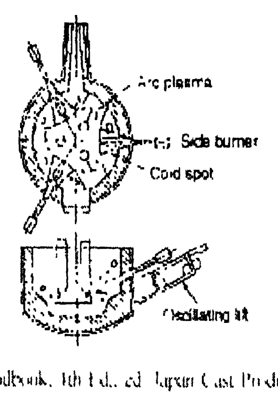
The melting period accounts for more than 50% of the total power consumption used in the entire arc furnace melting process. The operations, therefore, require skilled workers. The material composition and charging sequence recommended are:

- Requisite composition
- Light steel scraps: 60%
- Steel cutting scraps: 15%
- Pressed steel scraps: 15%
- Pressed steel plate scraps: 5%
- Returned steel scraps: 5%

Where charging is performed in three steps, it is recommended to adjust their weight ratio to 45%, 30% and 25%.

To save power, an oil burner is used to accelerate the melting of the fed material. In this case, the burner is fixed at a cold spot in the furnace to avoid the burning of the electrodes. A typical swing side oil burner is shown in Fig. 4.1.

Fig. 4.1: Swing side oil burner

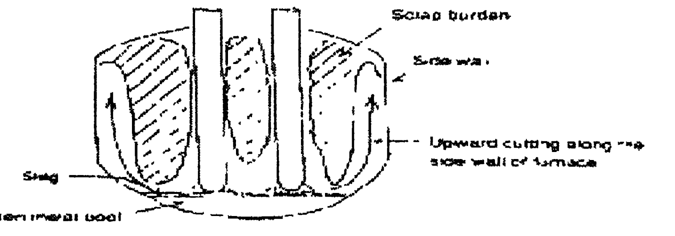


Source: Cast Product Handbook, 4th Ed., ed. Japan Cast Product Association

Oxygen lance cutting should be performed along the side wall of the furnace in a way that will not cause damage to the wall. Lance cutting, if required, should be

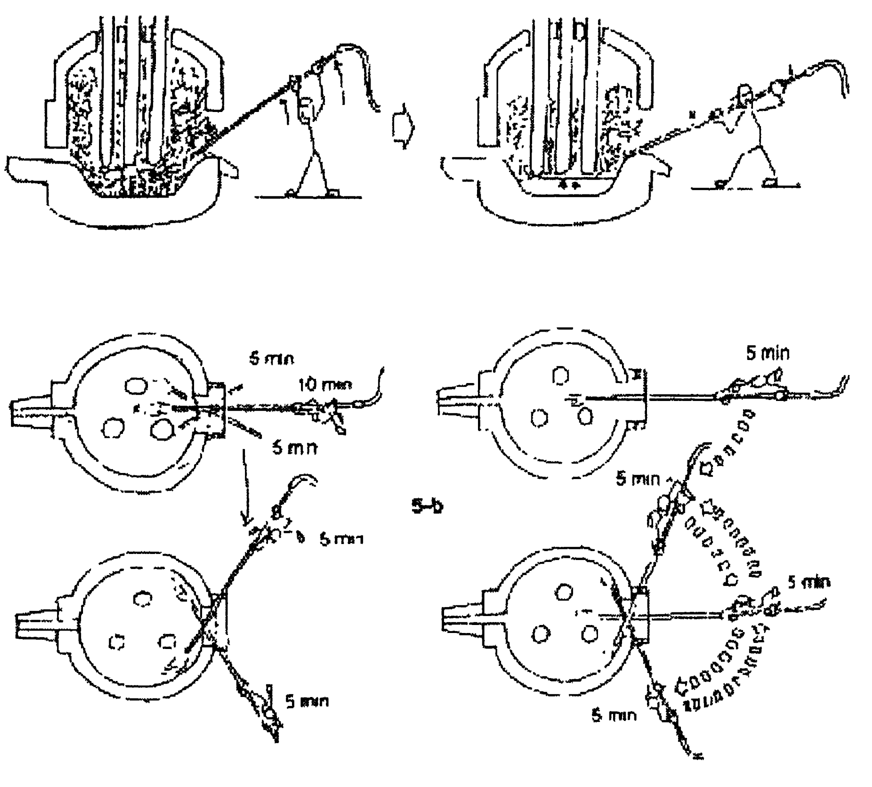
conducted as early as possible. The schematic is illustrated in Fig. 4.2. Thus, it should be started in about 15 min after the first charging, about 5 min after the second charging, and about 5 min after the third charging (time measured after the start of electric power supply). Typical design specifications of the oxygen lance pipe are: diameter of 20-40 mm, pressure of 5-10 kg/cm^2 , flow of 20-60 m^3/min and consumption of 5-15 m^3/h.

Fig. 4.2 : Cutting of oxygen lance



During heating, the oxygen lance should be inserted deep (50 mm or more depending on the furnace capacity) into the metal pool in the furnace so as to avoid damage to the electrodes, as illustrated in Fig. 4.3.

Fig. 4.3 : Oxygen Blowing Process in Oxidising Period



When bulky material becomes slightly red hot in the furnace, the canopy should be removed and the material compressed under an appropriate weight suspended from a crane, with power supply stopped for saving electric energy. Power supply should be resumed immediately after completing the compression.

The duration of compression under the weight should be 15 to 25 min after the start of power supply depending on the total weight of the material. This operation should be carried out quickly and therefore performed in close co-ordination with the crane.

Steel scraps fed in the furnace often contains undesirable components including soil, stones, scraped bricks and concrete debris, leaving large amounts of slag after the meltdown and reducing the fluidity. Slag should be removed as soon as possible.

Oxidising Period

Samples taken from the molten metal bath should be subjected to analysis of carbon, silicon, manganese and sulphur components to allow composition adjustment immediately before the start of the oxidising period.

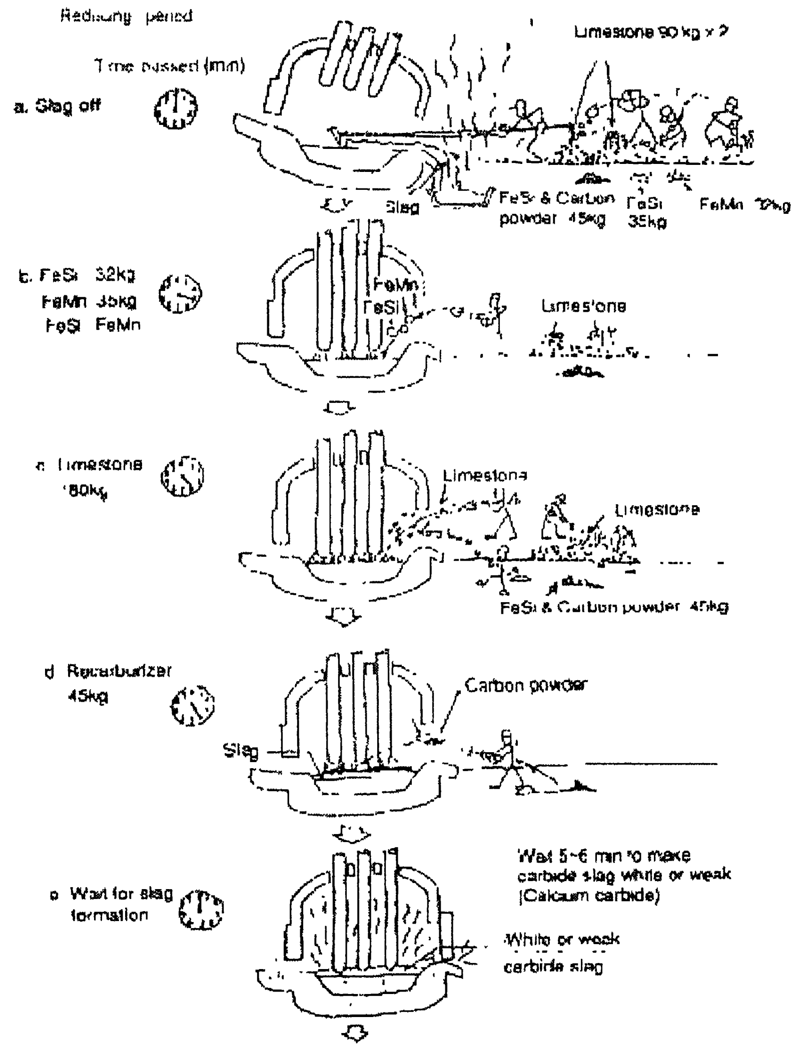
The oxidising period is important in accelerating major processes including de-phosphorisation, de-sulphurisation, de-carburization and de-oxidation. This requires a metal bath temperature of above 1,600°C. To achieve this, the voltage is decreased to increase the current. Oxygen blowing through the lance pipe should be performed during this period. The metal bath temperature should generally be above 1620°C at the end of the oxidising period.

Slag in the surface of molten metal bath should be removed completely at the end of the oxidising period.

Reducing Period

Scouring should be performed in the presence of basic slag to reduce the content of oxygen in the bath, which would have increased during the oxidising period. Simultaneous de-sulphurisation should take place, while adjusting bath composition and temperature. De-oxidation comprises diffused de-oxidation, which uses reducing slag and forced de-oxidation. Steel is taken out when the reducing slag is stable, after the rise of the bath temperature, marking the end of the scouring process. The operations are illustrated in Fig. 4.4.

Fig. 4.4 : Operation of Steel Making in Basic Arc Furnace Reducing Period



Cautions for Arc Furnace Operation

The steel making process through arc furnace melting is aimed mainly at the removal of undesirable elements such as phosphorus, sulphur, hydrogen and oxygen, and the adjustment of the composition for various components including carbon. These steel-making reactions are very sensitive when performed in the presence of high-temperature slag. What is most important, therefore, is to avoid the diffusion of heat out of the furnace and the inflow of air into the furnace. It is also essential to prevent the furnace from coming into a state, which is undesirable for the slag formation. In addition, the operations should be carried out quickly because their duration can affect the quality of the product.

Operations after Removal of Steel and Reduction in Duration

Reduction of time period until the start of the next melting process after the removal of steel is important in improving the steel removal efficiency and decreasing the power consumption.

Furnace repair materials, limestone, feed steel materials, etc., should always be kept ready to permit quick repair and charging of the furnace. Co-ordinated operations with the crane should be performed quickly and systematically. Adequate training of workers is essential to ensure this.

4.8 New Techniques for Energy Conservation

Innovations in the mini-steel sector have been driven by the need to reduce material, energy and capital costs. A number of such technological innovations from the developed countries, resulting in multiple benefits of conserving energy and improving energy efficiency, are available for adoption by the Indian industry. Some MSPs have introduced such measures in existing and upcoming plants such as:

Use of Water Cooled Panels and Roofs

The useful life of EAF sidewalls has been dictated by high wear rate of the hot spot refractories. These require frequent repair or replacement, while the remaining lining is in a good condition. Use of water cooled, side walls and roofs help to reduce refractory consumption by increasing lining life and reduced thickness of refractory lining.

A 75% saving in refractory materials costs and 50% increase in roof service life is feasible. The overall availability of the EAF is considerably increased. Long arc melting practice can reduce melting time by 5-10 minutes.

Oxygen Lancing

Use of oxygen during melting results in reduction of meltdown time, because of the exothermic reaction of oxygen with iron and other combustible elements in the scrap. The result is reduction in tap to tap time and saving in specific electrical energy consumption due to increase in furnace productivity.

Use of Water Cooled Chimney

High capacity furnaces of 15 t and above that use oxygen lancing / foaming slag practice may consider the installation of a water-cooled chimney. The chimney

will help in exhausting flames and fumes, which normally shoot up from the gap between the electrode and cooler. This increases electrode life and facilitates a cleaner shop floor.

High Power Transformers

A UHP transformer ensures high power input rate. Modern high-capacity EAFs have specific transformer capacities exceeding 800 kVA/t. The high transformer capacity can be optimally utilised by separating the refining operation outside the EAF.

This results in better thermal efficiency, quicker melting of solid charge particularly DRI/HBI thus substantially increasing productivity, optimum power utilisation and reduced power consumption. Saving in power up to 15 kWh/t has been claimed for large EAFs.

Scrap Preheating

Preheating the scrap in the charging bucket to 350 - 450°C by utilising heat of the waste gas from EAF could result in reduced energy consumption by 40-50 kWh/t, electrode consumption by 0.25-0.30 kg/t, refractory consumption by 0.82-0.12 kg/t, and heat time by 5-8 minutes. The system is, however, beneficial mainly for large capacity EAFs, 100% scrap heats and where extensive oxygen is used for melting and refining.

Foamy Slag Practice

Oxygen is injected with carbon to form a foamy slag caused by CO gas generation. The slag shields the arc radiation to the sidewall and roof and results in good thermal efficiency, reducing refractory wear, improved productivity, reduced power and electrode consumption and improved life of side wall panels and roof. However, slag pot capacity should be sufficient to accommodate lower bulk density slag.

Eccentric Bottom Tapping

Eccentric bottom tapping is a slag free vessel manipulation tapping system. A valve fitted at the bottom of the furnace controls the tap hole. Tapping is interrupted as soon as slag is detected in the molten stream. This provides good results in conjunction with residual liquid pool (hot heel) practice.

Furnace side walls can be covered about 87% with water cooled wall panels. Tapping temperature is reduced by 30°C, resulting in fast tapping

with compact stream, low gas absorption, clean steel and better lining life, and power saving of 10 - 15 kWh/t.

Oxy Fuel Burners

Oxy-fuel burners are used as source of auxiliary heating in the EAF. These burners help to increase the rate of heat input in case of a low power furnace. They reduce the maximum transformer rating and help to partially offset the effects of maximum demand of power. Other benefits include reduced melting time and increased productivity. These burners are discussed in detail in Appendix 2.

4.9 Recent Developments and Future Trends

The pace of technological development in EAF sector in India has been rather dismal as compared to some of the developed nations which, inter alia, forced a significant part of the industry out of business. However, there have been a number of new operating practices, which have evolved over the years, and have brought about a reduction in energy consumption also. These are discussed elaborately in Appendix 3.

4.10 Electricity Supply System

The use of energy efficient electrical equipment along with improved operating practices helps in controlling losses in distribution and equipment. Increasing efficiency means increasing the production or output for the same consumption of electrical energy or reducing the energy consumption for the same output. The index of energy efficiency for the plant as a whole is consumption of electricity per unit of production

Under the present constraints of cost and availability, the importance of electricity conservation needs no emphasis. Reduction in maximum demand load based on improved equipment demand control, power factor correction, improving power factor, energy efficient motor selection and utilisation and improved lighting practices can result in reduction in electricity usage of 3 - 5 % for the plant as a whole.

Load Management and Maximum Demand Control

Electricity demand and supply should match instantaneously. This needs reserve capacities kept to meet the peak demands. The cost of peak demand is normally referred to as demand charge. In India, at present, the demand charges do not fully reflect the marginal costs. Marginal demand charges are in the range of Rs.200

kVA/month. A review of tariff revisions indicates a tendency to hike the demand charges and also introduction of time-of-the-day metering. As such, there is a need for integrated load management to effectively control the maximum demand and its occurrence during peak/off peak periods of the power system.

When running of motors of large capacities are involved, it is advisable to stagger the running of these motors, where feasible, with a suitable time delay (as the process may permit) so as to minimise the simultaneous maximum demand (depending on conditions of load) drawn by these motors.

Shedding of Non Essential Loads

When the maximum demand tends to exceed a pre-set limit, it can be restricted by shedding some of the non-essential loads temporarily. It is possible to install direct demand monitoring systems which will switch off non- essential loads when a pre-set demand is reached. Simple systems give an alarm, and the loads are shed manually.

Savings in Electricity by Power Factor Improvement

Power factor is the ratio of actual power being used in a system expressed in kilowatts to the power which is apparently being drawn from the line expressed in kVA. Due to inductance within a system, the current lags the voltage, the effect denoted by `Power Factor or PF'. Improvement in PF facilitates better utilisation of existing capacity and some reduction in line losses. The higher the PF, better is the electricity use.

Improving /Correcting PF

The PF of a system can be calculated using a two part meter. Here two sets of kW and kVA readings before and after having run the known connected load for a few hours are to be recorded. The PF is given by :

$$\text{Average PF } (\text{Cos}\phi) \text{ at a given time} = \frac{\text{kWh}_2 - \text{kWh}_1}{\text{kVAh}_2 - \text{kVAh}_1}$$

In addition to the conventional methods, on-line power factor meters are available, which can be used to measure PF of a particular load directly. The measurements can be done without/interrupting the load. Knowing the PF, the rating of capacitor in kVAr required for a given load (in kW) can be computed using a multiplication factor.

Suggested measures to improve PF (to be considered as applicable)

* Use of capacitors, capacitors can be bought in unit modules blocks and combined to provide the required amount of capacitance. Capacitors should be installed preferably at the terminals of offending loads rather than for the entire system.
* Use of synchronous motors instead of or along with induction motors. Characteristics of synchronous motors are such that they can be operated at unity or leading PF.
* Use of synchronous condenser, which is a rotating equipment similar to a synchronous motor. This drives no load, but merely functions to improve PF.
* Use of high PF equipment (e.g., high PF lighting, ballasts) and electric resistance devices (e.g., boiler, furnaces, etc.,) and operation of equipment at close to full load.

4.11 Electric Drives

Motors should be chosen considering machine load at start and during running. The annual cost of electrical energy consumed by a motor is 2-3 times the initial cost of the motor itself. This emphasises the need for choosing energy efficient motors, even if they are slightly more expensive. The energy consumption in motors is based on the efficiency of the driven equipment and the system. One of the main reasons for inefficiency is routine under-loading. Often, high capacity motors are selected to meet initial torque requirements.

Table 4.5 : Savings from higher efficiency motors (rating 20 HP/14.9 kW)

Parameters	η = **87%**	η = **93%**
Initial cost (Rs.)	24000	32000
Annual capital charges @ 20% for 10 years life	4800	6400
Input power (kW)	17.15	16.04
Power consumption/year in units (8000 h)	137200	128320
Electrical charges @ Rs. 4/- per unit	548800	513280
Total recurring cost (Rs.)	553600	519680
Total savings/year (Rs.)	-	33920

Most motor driven equipment such as fans, pumps and compressors are subjected to varying load. These systems are designed for a maximum duty condition that rarely occurs, with the result that they run for long periods at less

than maximum flow. The reduction in flow is achieved by dampers, throttle valves or by-pass systems, all of which are energy-inefficient. Substantial savings can be made if the system is altered, so that control is achieved by varying the speed of the motor instead. Relevant conservation measures for the motors and drives include:

Proper Loading of Motors

Medium Term

Soft starters and energy savers avoid the selection of high capacity motors. Soft starters are solid-state electronic components, which control input voltage according to starting torque required for the driven equipment, resulting in smoother starting of motors by drawing lower current. The high instantaneous current at start is avoided. Energy savers also control voltage and current according to the load. They are most economical in motors, loaded less than 50 % for more than 12 hours a day.

High Efficiency Motors

Medium Term

The cheapest motor does not imply the least expensive one. Running costs must be considered with capital cost when selecting a motor. Motors that drive fans, compressors and pumps, where variation in throughput is required continuously, can be replaced by high efficiency motors to reduce energy intensity. These may weigh a little more, be slightly larger in dimension and cost about 30 % more. However, as they consume less power, the extra cost is soon recovered. Their higher PF implies less expenditure on power factor correction equipment.

Motor Protection Relays:

Medium Term

For important and strategic motors, it is advisable to use motor protection relay to avoid motor burning, which could prove costly both in terms of loss of motor as well as production downtime.

Conversion of V-belt Drives to Flat Belts

Medium Term

In a mini steel plant, major motive loads like air compressors and pumps utilise belts (V- or flat belts) for power transmission. In V-belts, thick rigid sections absorb a great deal of useful power and add to the running costs. Transmission efficiency of V-belts is between 83-86%.

In flat belts, transmission efficiencies of up to 98% are feasible. A modern flat belt consists of a nylon fibre core sandwiched between the frictional face of synthetic rubber. The high tensile strength of the nylon core helps transmit loads without

stretching. Chrome leather, which has a high co-efficient of friction and high resistance to abrasion, makes the flat belt more energy efficient.

Another factor in favour of flat belts is the lighter weight of the belt. Theoretically, the power transmitted by any width of belt increases in direct proportion with its speed. In practice, centrifugal force increases in proportion with the weight of the belt and the square of its speed. Flat belts are one-third the weight of comparable V-belts. The energy required to move a heavier cross-section to a given distance is greater than that required for lighter weight belts, thus contributing towards energy savings when flat belts are used.

Motors that are not loaded to at least 60 % of their rated loads are relatively inefficient and cause reduction in the PF of the entire electrical system. This, in other words, implies more current drawal for the same power delivered. Low PF also increases losses in electrical distribution and utilisation equipment such as cables, motors, transformers and have an adverse impact on their life.

4.12 Lighting System

Short/ Medium Term

An energy audit of the lighting system will reveal the efficiency of the existing system. Although lighting contributes very little to the overall energy profile, this is also an area of little attention and consequently, the most neglect. The various energy conservation measures applicable for lighting systems are discussed in this section.

Low efficiency incandescent and fluorescent lamps such as tungsten filament lamps (GLS) can be replaced by fluorescent lamps or high-pressure mercury vapour lamps (HPMV) or by high-pressure sodium vapour lamps (HPSV). Where it is difficult to change from incandescent lamps to more efficient lamps (HPMV or HPSV), the blended light lamps (MLL) provide an interesting alternative with no additional investment, as they are a plug-in replacement. The most common way of comparing light sources is to compare their efficiencies defined as output luminous flux (lumens) over the power input (kW).

Most discharge lamps display a gradual reduction in light output over the years. These should be replaced at the end of their economic life even if they do not fail. More supplementary lights, e.g., twin tube luminaires should be provided in the region further from the windows and less supplementary lights, e.g., single tube luminaires near the windows. A 1 m reduction in height of the ceiling can reduce 20-30% energy consumption by way of lower lighting requirement. Painting walls and ceiling with light colours can reduce artificial light requirements. Unnecessary

lamps can be removed or switched off, preferably by a timer switch. Natural light can be effectively used by providing large fibreglass skylights and high openings in the walls. Periodic cleaning of lamps and windowpanes will ensure full utilisation of daylight and artificial lights.

A slight reduction in operating voltage, in case of fluorescent tubes, would result in savings without affecting lighting levels appreciably. A separate voltage regulator, which supplies about 380/390 volts to the lighting circuit, be used. In large/medium scale industries, where the lighting consumption is high, it would be economically viable and technically feasible to have a separate 11 kV/240V – 3 phase transformer, exclusively for lighting circuits. Scheduling controls help eliminate unnecessary use of lighting. Timed switching controls ensure lighting systems are turned off, according to an established schedule. These devices range from simple timers to programmable sweep systems.

Some effective ways of conserving energy in lighting include:

Standard Operating Routines

There should be a "Switch Off" campaign or installation of automatic switching or dimming equipment. The use of local switches for both lamps and fans should be encouraged. This will enable control of lighting near the source itself.

Daylight Conservation

Use daytime more effectively.

Maintenance Measures

It is worthwhile maintaining a regular cleaning schedule for all lamps and fittings. This will ensure that optimal light availability is maintained.

Section 5 : Case Studies

5.1 Energy Savings Due To Oxygen Lancing

Use of oxygen-assisted melting resulted in reducing the power-on-to-tap time by 30 minutes in one of the units, which in turn resulted in the production of an additional heats per day. The benefits achieved in the modern Electric Arc Furnace by the introduction of oxygen lancing are given in Table 5.1.

Table 5.1 : Benefits of Oxygen Lancing

Oxygen Consumption Nm^3/t	Charge-to-tap time (min)	Electricity Consumption kWh/t	Output t/h	Pig-Iron %	Yield %
1.9	160	561	27.84	4.8	94.2
5.0	150	551	30.26	5.7	94.2
13.7	129	519	34.68	11.9	93.0
21.0	119	473	37.76	18.7	93.0
27.0	112	463	39.75	26.3	91.3
37.2	103	485	39.40	37.5	89.0

5.2 Energy Saving Due To Scrap Preheating

The exhaust gas evolved from EAF consists of 15-20% of the total energy input. The average flue gas temperature is about 1520°C and during oxygen lancing is still higher. This heat in the gases can be effectively utilised to preheat the scrap charge to a temperature of about 250°C resulting in energy savings. This is shown in the following calculation.

Scrap preheat temperature	=	250 °C
Heat required to heat the scrap from 30°C to melting temperature	=	1000 X 0.7 (250 - 30)
Savings in energy	=	1.54×10^5 KJ/Lt

5.3 Waste Heat Recovery from Hot Air Venting from FD Cooler

From the material balance of the EAF the water equivalent of the coke moisture of 7.5% was 260 kg. The energy for vaporisation of this water is taken from the bath to dry it to an equivalent coke moisture content of 2%.

$$\text{Moisture evaporate} = \frac{7.5 - 2.0}{100} \times 3460 = 190 \text{ kg.}$$

$$(3460 \text{ kg} \approx 260 \text{ kg} \times \frac{100}{7.5}$$

It is clear from the energy balance that heat in bath (slag + metal) forms 65% of electrical power input.

Latent heat of vaporisation	=	583 kcal/kg
Heat required to evaporate 190 kg of water	=	190 X 583 kcal
Energy savings per heat from latent heat of vaporisation not drawn from the bath	=	$\frac{190 \times 583}{0.65}$
	=	170415.4 kcal
	=	198.1 kWh
∴ Annual savings @ 10 heats/day and 300 days/year	=	5.94 lakh kWh

This heat can be obtained by waste heat recovery of the hot air venting from the FD cooler. Approximately three tonnes of ferro-alloys and fluxes are added in the ladle in each heat.

Assuming that the temperature of these additives can be raised by 30°C, and 50 kg of water can be evaporated from the lime addition in LRF, the heat in metal and slag in the ladle can substitute 31.1% of electrical power input.

Energy savings/heat	=	$3000 \times 30 \times 0.16 + \frac{50 \times 583}{0.31}$
	=	108432 kcal
	=	126.1 kWh
Annual savings @ 10 heats/day and 300 days/year	=	3.78 lakh kWh
Total annual savings	=	9.72 lakh kWh
	=	Rs. 24.3 lakh
Total heat required for heating and drying	=	154320 kcal

Assuming Δt of $5^{\circ}C$ in hot air,

Heat available per hour in hot air	=	248670 X 1.29 X 0.21 X 5
	=	336823.5 kcal

∴ Heat available in hot air is more than the calculated requirement of heat energy and hence sufficient.

It is estimated that an investment of Rs.35.0 lakhs would be required to fabricate the insulated duct and heating chamber.

Simple payback period = 1.44 years

5.4 Charge Composition affects Energy Savings

A foundry unit with an annual production of 5000 tonnes has two 4-T arc furnaces. Charging the furnace with material of unknown composition results in wide variation in opening carbon. This results in increased production costs by way of increased oxygen and higher energy consumption. The company also uses borings and turnings in the EAF charge. Since the density of this charge is very low, the company can save energy by bundling the turnings and borings.

The present power-on to tap- time is 3.5 hours. It is estimated that by using a charge of known composition and bundled turnings and borings, the power on to tap time can be reduced by 20 minutes per heat. The annual energy saving for a production of 8600 tonnes of liquid metal at 7 heats per day, 300 days per annum is Rs.8,19,000. An investment of Rs.3.5 lakh will have to be made towards purchase of a bundling machine.

5.5 Oxygen Assisted Melting

Use of oxygen assisted melting resulted in reducing the power on to tap time by 30 minutes in one of the units, which in turn resulted in the production of an additional heat per day. In another foundry where oxygen assisted melting was practiced, the plant has achieved a specific energy consumption of 726 kWh with a production of seven heats per day as against 774 kWh without oxygen lancing at a production rate of six heats per day. The lining life with oxygen assisted melting was however reduced marginally. It has also been reported that foundries with severe power cut (of the order of 60%) were using oxygen to the extent of 80-100 cubic metre per tonne to achieve the required production. The lining life was only 60-80 heats in such cases.

5.6 Optimisation of Furnace Operation

A foundry with an annual production of 5000 tonnes of castings has two arc furnaces of 4- T capacity each. By operating both furnaces, around seven heats are tapped per day. It is envisaged that the current production level can be achieved by operating only one furnace with oxygen assisted melting. Oxygen aided melting would result in:

1. Reduction in peak demand.
2. Reduction of specific energy consumption.
3. Additional liquid metal production.

It is estimated that, oxygen aided melting would result in an annual saving of 3,88,000 kWh and the additional production would be around 1350 tonnes. The cost for oxygen would be 4,86,000 and the net savings would be Rs.97,000 per annum. These prices are estimated at prevailing tariffs at the time of the audit.

5.7 Reducing Delays

The following analysis was carried out at a foundry producing about 6000 tonnes of good castings per annum. The company has two direct arc furnaces of 5 tonne capacity each. A delay analysis as shown in Table 5.2 revealed the following.

Table 5.2 : Delay Analysis

Nature of Delay	% of Total Heat	kWh/tonne
Electrode Sparking	20	820
Ladle Assembly	4	814
Opening Carbon	4	826
Crane / OCB Failure	7	790
Load Shedding	10	872
M.D. Controller	2	808
Nil Delay	45	724
Other Delays	8	-

Specific consumption without delay = 724 kWh/tonne
Specific consumption with delay = 815 kWh/tonne

The company has been successfully restricting its peak demand through an M.D. Controller. The demand reduction of 400 KVA which the company has been able to achieve far outweighs the energy loss due to delays.

The average number of heats per month is 140, of which only 63 (45%) are tapped without any delay. Increasing the nil delay heats from 45% to 70%, about 78 heats can be tapped without any delay. The resultant energy saving due to the additional 35 heats tapped without any delay is 15925 kWh at 5 tonnes of liquid metal per heat. The annual electricity saving would be 1,91,100 kWh, resulting in a monetary saving of Rs. 2,10,210. The investment required would be towards the maintenance of auxiliary equipment.

5.8 Industry Case Study 1

The plant has two GEC make EAFs, each with a rated holding capacity of 20/23 Mt. The furnace transformer rating is 12.10/13.55 MVA with 9 taps with off-load tap changer. The molten metal is tapped in a ladle of capacity 20 T through the tapping spout. The furnace has water-cooled side walls and furnace roof. The roof has only three holes for electrodes and the exhaust fumes escape from the electrode openings and slag door. The fumes are extracted through a fume hood.

Operating Practices

The scrap quality is good with a high bulk density and minimal dust, rust and other impurities. The furnace is charged only once during a heat by a charging bucket. Initially, coke and limestone are charged and then scrap is added on top. The roof is then shut and the arc initiated. The electrodes are cooled externally by spraying water on them. Hot heel practice is not followed in the plant.

The specific energy consumption fluctuates between 560 and 730 kWh per Mt. of tapped metal. The electrode consumption is nearly 6.25 kg/Mt. The oxygen consumption is about 250-300 Nm^3 / heat.

The arcing period is between 120-140 minutes. This is because, after arcing for 70 minutes at high tap, a molten bath is formed but there is still substantial scrap at the periphery of the furnace. The scrap has to be melted but arcing has to be done at lower tap as the arc becomes naked and higher tap setting would mean excessive loss and heating of roof and wall refractories. The scrap sticking to the sides also poses the problem of suddenly falling into the bath and creating unstable conditions in the furnace.

Another reason for prolonged arcing time is the low voltage received at the furnace. This results in very low rate of energy being released by arcing even at high taps resulting in higher energy consumption. The longer duration of furnace arcing results in more losses as heat is being continuously lost via the cooling water, exhaust fumes and radiation and convection from the furnace shell.

The shell temperatures revealed no excessive losses. Outer surface temperatures were below 60°C on the surface above the slag line and 140°C below the slag line. Refractory consumption is higher due to longer heating and naked arcing.

Specific electrode consumption is also higher particularly because the hot exhaust fumes vent from the three electrode holes and not from a separate fourth hole. This is despite the external electrode cooling arrangement.

An energy balance for the furnace revealed that, on an assumption of 20 tonne of metal tapping at 1710°C in each heat with a power consumption of 13000 kWh, the heat given to metal is nearly 61.6% of the electrical power input. An additional 6.6% heat is given to the slag. Cooling water from the water-cooled cables and armatures carry away nearly 8.5% of the power input. The radiation and convection loss from the furnace shell is only 3.4%. The water-cooled panels contribute 3.1% of equivalent power loss. The remaining 16.7% of power input is lost through hot exhaust fumes, thermal inertia of the furnace and roof, directly radiated out by the arc. Some suggestions for energy conservation included:

Installation of Sidewall Oxy-fuel Burners

EAFs are typically characterised by the presence of cold spots depending on the shell shape, size, capacity and operational conditions. Non-optimal thermal distribution, especially at the periphery of the furnace walls results in non-uniform melting due to temperature difference and sudden collapse of scrap. An energy audit revealed that the scrap charged had a high bulk density, which resulted in scrap near the walls remaining solid even after formation of a molten bath at the centre. From this point of time, after nearly 70 minutes of initiation of arc, the

power input to the furnace should be reduced so that the scrap sticking to the sides can gradually slide into the molten bath. The arc becomes exposed and most of the energy radiates to the walls and the roof. The energy for melting the metal sticking to the sides can come only from the bath.

An oxy-fuel burner is used for efficient, rapid melting of scrap by substitution of electrical power with directional heat input from liquid or gas fuels. Oxy-fuel burners should be introduced through the slag door firing across the cold spots to maximise flame to scrap contact. They can also be fixed on the sidewalls or the roof for better access to the cold spots. They can ensure quicker and more uniform meltdown to reduce power consumption by nearly 40 kWh/Mt. of steel produced. The reduced energy demand can be met by using liquid fuel firing oxygen burners.

The initial cost for an arrangement of oxy-fuel burners on both the furnaces would be Rs. 80.0 lakh. The annual energy savings would be Rs. 132 lakh from a power saving of nearly 33 lakh kWh replaced by suitable liquid fuel. The simple payback period is about 8 months.

The biggest advantage is that some of the energy required for the EAFs is met by liquid fuel and consumption of electrical power, a scarce input, is reduced.

Installation of On-line Tap Changer on 66/11 kV Transformers for EAFs

The incoming voltage to the EAF varied between 7.8 to 9 kV, when the grid voltage was low. This resulted in longer heat time in the furnace and higher specific energy consumption. The total energy consumption per heat increased by 1500-2000 kWh for the same quantity of metal tapped. The voltage received on the 66 kV cannot be corrected on the 11 kV secondary of 15 MVA transformers, since they transformers only off-load tap changers.

On-load tap changer should be installed on 66/11 kV, 15 MVA transformers. This will help improve voltage loads received on the primary of the furnace transformers and reduce energy consumption by 2000 kWh per furnace per day. This amounts to an annual energy saving of 12-lakh kWh equivalent to Rs.48

lakh. The investment required is Rs 60 lakh. The simple payback period is 1.25 years.

5.9. Industry Case Study 2

The 50/60 T EAF has been supplied by Demag of Germany. The EAF was originally operating on 100% scrap charge. With the backward integration of a Direct Reduction Plant in the unit, since sponge iron was available, the charge was modified to a mix of scrap and DRI. In early 1993, an experiment was conducted using 100% DRI charge with continuous charging and DRI with 20T-scrap charge.

Since the refractory wear was much more in the 100% DRI heats, in order to repair the refractory lining a furnace shutdown was taken after every 7-8 days of continuos operation. The lining was also patched up by castable magnesia gunniting between heats. The heat immediately after a refractory lining repair or a weekly shutdown had 20 T of scrap charge.

Energy Consumption

Since the charge composition varies, the specific energy consumption also varied between 790 to 850 kWh per MT of billet. The specific energy consumption is higher for a 100% DRI heat by 17% than for a scrap-plus-DRI heat. After a weekly shutdown, the specific energy consumption is about 11% more than a normal 20 T scrap heat but 7% less than a 100% DRI heat. The variation of 2-4% could be attributed to varying percentages of metallisation in DRI, as any unreduced oxide adds to the thermal energy required to melt the charge.

The carbon content in the charge determines the extent of boiling and foaming necessary to cover the naked arc, to enable high power input during continuous charging. DRI is a low-carbon charge, requiring external coke addition to achieve the necessary effect, however, at the expense of higher energy consumption.

The instantaneous power factor to the EAF varied between 0.70 to 0.96. The power factor depends upon the length of arc. Computerised melt control

systems are now available in Europe and USA, which maintain optimal PFs by measuring secondary reactance, computing electrical power and energy balances, and controlling the electrode position at a steady-state value. A melt control system would cost approximately Rs. 6.0 crore and savings envisaged are 7-8%. However, this is a long term measure in view of the high investment.

Material Balance

Since only a few of the material inputs and outputs can be measured, the others can be estimated only after establishing a balance. A material balance for a typical heat with 100% DRI charge includes the following:

Inputs: Measured inputs include DRI, calcined lime, coke, burnt dolomite, charge and injected oxygen. Assessed quantities include electrode consumption of 3.774 kgs per MT, refractory erosion quantity based on average thickness of refractory eroded per heat, at 2 mm per heat. Experienced melters can estimate the quantity of molten heel left over from the previous heat and the slag on top of the heel. Compressed air is assessed from actual measured data from the past.

Outputs: Measured outputs include metal tapped, dust in the furnace, velocity of exhaust gases at the break flange and slag. Estimated quantities include molten heel and slag in the furnace after tapping. Since the composition of gases is different before and after the introduction of oxygen lance, the quantities have been separately shown in the balance. About 10% of the exhaust gases escape through the electrode holes and the fifth hole in the roof.

The fourth hole for evacuation of gases and the hole for continuous charging are adjacent to each other. A small amount of charge is sucked into the gas duct and contributes to high dust amount. Around 700 kg of free carbon is evacuated through the exhaust duct and burnt in the After Burning chamber. This contributes to a higher quantity of CO_2 and CO in the gases for measurements taken before the safety damper as compared to quantity of CO_2 and CO at the break flange. The balance is illustrated in Table 5. 3.

Table 5.3 : Material Balance

Input in MT				Output in MT			
	Fe_m	Fe in FeO	Fe Total		Fe_m	Fe in FeO	Fe Total
Hot heel	11.16	-	11.16	Metal tapped	55.53	-	55.53
DRI	49.45	7.38	56.83	Hot heel	9.89	-	9.89
Slag in heel	-	0.22	0.22	Slag	-	2.31	2.31
				Slag in heel	-	0.15	0.15
				Dust	-	0.13	0.13
Total	60.61	7.60	68.21	Total	65.42	2.59	68.01

Energy Balance

On the basis of the material balance an energy balance for the same heat was computed. The temperatures recorded are shown in Table 5.4.

Table 5. 4 : Temperatures of Input Parameters

Material	Temp in ° C
DRI	70
Burnt Dolomite	28
Coke	26
Char	29
Calcined Lime	38
Ambient Air	29

The metal was tapped at 1605° C. The temperature of the exhaust gases varied between 993 and 1191° C at the break-flange. Water-cooled panels were used for walls, roof and roof elbow to minimise the refractory cost. The flow was measured while temperatures were recorded at 3 minute intervals. The temperature of the soft water in high pressure cooling circuit was simultaneously measured.

The balance remains incomplete as the percentage of unaccounted output energy is nearly 24%, because nearly 1.45 MT of carbon could not be accounted for in the output of the material balance.

The energy balance for the EAF indicated that 29431.1 kWh of electrical power is given to the batch i.e., metal, slag and heel. This is 66.4% of the 44307 of total electrical power supplied to the batch. Heat given to metal tapped is 45.7% of the electrical power input. The detailed energy balance is shown in Table 5.5.

Table 5.5 : Energy Balance

Energy Input	**kWh**	**%**	**Energy Output**	**kWh**	**%**
Electrical energy	44307.0	72.7	Heat to metal	20237.6	33.2
Oxidation of Electrodes	1671.5	2.7	Heat in slag	8976.0	14.7
Heat of Reactions	15007.4	24.6	Heat to motion heel.	217.5	0.3
			Heat carried away by cooling water in walls.	2638.3	4.3
			Heat carried away by cooling water in Roofs.	4613.6	7.6
			Heat carried away by cooling water in Roof Elbow.	2065.4	3.4
			Heat carried away by cooling water in high pressure system	574.9	1.0
			Heat carried away by exhaust gases.	5892.7	9.7
			R & C Losses	1208.8	2.0
			Sub-total	46424.8	76.2
			Unaccounted	14561.1	23.8
Total	60985.9	100.0	Total	60985.9	100.0

6.44 MT of FeO is reduced yielding 5.01 MT of Fe metallic. The total FeO was 9.77 MT thus 65% is reduced.

Certain measures to reduce energy consumption include :

Preventing Overshooting of Boiling Temperatures

Boiling temperatures overshoot tapping temperatures at least twice a day to as high as 1680-1690°C. The outer surface temperatures were recorded with bath temperature at 1664°C and are clearly higher by 20°C. The corresponding surface losses were 10% higher than normal operating conditions. The water-cooling and exhaust gas losses also increased.

Stricter control on boiling temperatures would reduce surface and other losses. The practice of increasing DRI feed rate with abnormally high bath temperatures only taps the excess heat in the bath, but cannot curb the losses.

Since radiation and convection losses are a small percentage of the total energy and the temperatures overshoot, when the heat is nearing completion, the savings are too small to be quantified. Control on boiling temperature would also translate into longer service life of refractories.

Switching Off FD Cooler Fans between Heats

The three FD cooler fans consumed 99.4 kWh and ran continuously for 24 hours, even between heats, when exhaust gas temperatures are much below the maximum permissible temperature of 130°C at the bag filters. Switching on and off of the three fans could be connected with the exhaust gas temperatures of EAF. A thermistor controlled switch could be provided for switching off a fan after the temperature of the exhaust gas falls below a preset value between heats and the fan could be switched on when the temperature rises. A small difference in the temperature settings of the three fans would avoid simultaneous starting of the three fans.

Annual savings of 1.79 lakh kWh or Rs.7.16 lakh are envisaged, at a cost of Rs. 6.0 lakh with a simple payback period of less than one year.

Waste Heat Recovery from Hot air exiting from FD Cooler.

The exhaust gas is cooled to ensure its temperature is below 130°C at bag filter entry by forcing ambient air by FD fans over vertical tubes through which the hot

exhaust gases flow. The ambient air, in this cross flow heat exchanger gets heated up and is discharged into the atmosphere.

The flow of air was measured at 2,48,670 m^3/hr at 29°C. The temperature of the hot air at the top and bottom of the outlet of the FD Cooler were measured for a complete heat of 85 minutes in the EAF.

Temperatures Recorded:

Ambient	:	29°C
Outlet Air	:	33°C before start of heat.

The temperature of the air at the bottom outlet point rose to 49.6°C and then to 79.1°C after 5 minutes and 8 minutes respectively of starting the heat. The temperature at the top and bottom of the FD cooler were 56.5 and 88.2°C respectively.

The temperature of the hot air at the top varied between 127.8°C and 250.5°C for the remaining period of heat and at the bottom between 110.8°C and 173.1°C. The minimum and maximum temperature variations coincide for both points as these are dependent on the temperature of the exhaust gases. The average temperature of the hot air can thus be calculated from the mean temperature of these two points as 119.3°C and 211.8°C respectively for a period of 75 minutes. In fact, even after 12 minutes of heat being over, the average temperature of the hot air was 106.2°C.

The hot air from the FD cooler can be used for drying coke charged into the EAF. Most ferro-alloys and fluxes added to the LHF pick up moisture from the ambient, which can also be dried by the hot air.

This required an insulated duct to be designed and installed for collecting hot air emanating from the FD cooler, to be fed into drying chambers where it is to be passed over the material to be dried. The saving estimated is Rs. 43.4 lakh with an investment of Rs. 56.0 lakh for a simple payback of 1 year 4 months.

Section 6 : Check List for Energy Saving Opportunities

Development of an energy conservation programme can provide savings by reduced energy use. However, it is economical to implement an energy conservation program only when savings can offset implementation cost over a period of time. Potential areas of conserving energy and a logical analysis of the methods or techniques of conservation would provide a systematic and disciplined approach to the entire conservation strategy as a sequel to the energy audit. Some established conservation trends are replacement, retrofit, process innovation, fuel conversion and co-generation. **The ABCs of Energy Savings** can be used as a checklist to identify the areas of deficiency and adopt the right approach for energy savings. It is far from complete, but does serve to indicate different types of energy measures.

A	B	C
Adjustable frequency drives Ambient air reset controls Analysis of audit results	*Balancing energy Blow-down controllers Burner efficiency*	*Co-generation Compressed air leakage control CO_2 and O_2 in flue gas*
D	**E**	**F**
Demand control Delay monitoring and avoidance DDC management systems	*Economiser controls Efficient equipment selection Energy audit and analysis*	*Flue gas heat recovery Filter loading control Fan efficiency optimisation*
G	**H**	**I**
Gas analysis Gas cutting techniques General housekeeping	*Heat energy tracking Heat recovery methods High efficiency criteria*	*Insulation Infiltration control Inspections*
J	**K**	**L**
Job-task analysis Joint sealing and testing Justify retrofits	*Kiln Efficiency Kwh and kw reduction Keep temperatures optimal*	*Lighting Load calculation/ shedding Life-cycle cost analysis*
M	**N**	**O**
Maintenance Metering Monitoring	*Non conventional methods Novel technologies Natural gas use*	*Occupancy sensors Optimisation Over-rating avoidance*
P	**Q**	**R**
Peak demand shaving Power factor corrections Pay-back period	*Quality*	*Retrofits Return air systems Refractories*
S	**T**	**U**
Solar energy Soaking pit optimisation Selection criteria	*Time of day Thermostat settings Temperature control*	*U-values Utilities Utility meter close to site*
V	**W**	**X,Y,Z**
Variable air volume boxes Variable supply air setpoint Voltage selection	*Water conservation Waste heat recovery Water treatment*	*XTMR losses Yearly cost and savings Zone controls*

In addition to these basic checklists, the sections below deal with individual equipment to serve as a quick and handy **reference**, aimed primarily at shop floor personnel.

Power Factor Improvement

Install capacitors with phasitron control to modulate reactive power
Maintain peak load PF around 0.95 and use storage facility for peak hour requirements
Provide alarm system in maximum demand indicator
Restrict starting and stopping of high HP Motors simultaneously, staggering working and recess timings and avoiding idle running of machines
Operate and transfer high unit loads judiciously
Verify existing PF and redesign capacitors, selecting low dielectric loss capacitors
Ensure powerhouse is informed before switching on heavy loads.

Provide programmable timer based controls for exhaust fans
Flatten load curve and maintain a high load factor

Motors

Motor loss increases with voltage imbalance.
Avoid under-loading, as efficiency is low at 50% loading, with lower PF.
Install variable speed motor depending on process variations
Never use loose or excessively tight 'V' belts.
Try DC variable frequency drives instead of slip motors
Adopt proper maintenance practices to avoid friction losses.
Install automatic control to switch off idle motors
No size-load mismatch should occur, but choose highest motor speed

With high duty cycles, use high efficiency motors
Ensure replacement of rewound motors by standard motors
Low starting torque can increase by soft starters and energy savers
Lubricate bearings regularly and provide proper lubrication and ventilation

Lighting

Shun use of incandescent/tungsten filament lamps.
Weigh maintenance requirements and clean luminaries, ceilings, walls regularly
Install local switching for control of light fixtures and dimmer controls for flexibility

Try to locate workstations requiring most illumination near windows
Consider photocells and time clocks for turning exterior lights on and off.
Have translucent roofing sheets and maximise day light use

Operate electronic ballast of good make instead of conventional choke
Facilitate localised or task lighting consume less energy than general lighting
Favour selective switching of luminaires

Lower tap of isolating transformer to separate lighting load
Isolate lighting and ceiling fan circuit
Gauge surrounding décor and paint walls accordingly
Have fluorescent lamps in stairways, corridors, toilets and task areas
Try to use voltage controllers alternatively for discharge luminaires
Stagger 3-ϕ loading from poles and use 4-core cable for street lighting

Sub-Stations and Transformers

Adopt split bus system in substations to allow flexibility of operation
Distribute load to optimise loading after identifying under-loaded transformers
Have locations near load centre to minimise losses and improve tail end voltages
Ensure operation of identical transformers in parallel whenever required
Rotate cyclically and switch off idle transformers on primary side
Ensure transformers are switched off on holidays and power cuts

Try to provide a separate lighting transformer
Operate circuit breakers and disconnectors for transformers without fail

Select and use transformers with lower losses
Test tap positions of distribution transformers seasonally and re-adjust
Apply instrumentation for monitoring individual transformers
Never select power transformers without OLTC and auto control.
Distribute/ load bus bar sections parallel paths in sub stations equitably.

Distribution System

Add separate distribution switchboards for power and lighting circuits
Restrict LT distribution by increasing HT distribution

Draw balanced multiple circuits from secondary of transformers

Operate ring main system for HT & LT systems for flexibility
Provide parallel paths and multiple cable runs to balance load to 1%
Ensure cable carrying capacity in tune with requirements of machines
Replace old paper cables by new PVC/XLP cables
Ascertain equal distribution of loads on available parallel paths
Transfer and redistribute loads to avoid circuitous feeding
Install capacitors near load points or at sub-distribution board.

Motor Drive Installations

Never use oversized equipment
Gauge voltage at points of use and avoid voltage imbalance

Provide capacitors with higher voltage rating than supply voltage
Replace stalling high torque drives with hydraulic cylinders/ fluid couplings
Adhere to schedules and train operators for timing
Connect capacitors across motor terminals of heavy duty motors
Try to start motor with a contactor for heavy duty Y-Δ installation
Install automatic controls and timers for optimum operation
Choose photocell control or long arm limit switch to shut off idle conveyors
Ensure squirrel cage motor reversing is withheld till speed has dropped to 60%

Compressed Air System

Substitute pneumatic instrumentation by electronic instrumentation
Test system availability and check logs periodically
Operate solenoid cut off valves in the air system
Provide extra air receivers and reduce delivery pressure where possible

Lubricate all pneumatic equipment properly
Ensure operation of pneumatic equipment at recommended pressure
Assess lubricating oil consumption, misalignment, debris and damages
Keep compressor valves and nozzles in good condition
Allow one small compressor handle load variation, with rest at full load
Gauge using hot compressed air for heat recovery and regenerative air dryers using heat of compression
Ensure minimal 'No-load' operation

Optimise automatic electronic moisture drain trap timings
Facilitate delay timers to limit number of motor starts

Clean cooling towers, fouled inter-coolers and air inlet filters regularly
Operate blow guns for clearing off swarf or moisture at low pressure
Monitor pressure drop by installing manometers across filter
Provide control by inter-linking water temperature and fan operation
Retrofit modern speed regulation controllers in big compressors
Ensure air intake is not warm and humid
Support installation of solenoid valves in the cycle punch press blow-off nozzles
Substitute two-stage or multistage compressor for large single stage ones
Ensure FAD and no-load tests are carried out periodically
Discourage misuse of air

Avoid oversized compressors and screw compressors at partial loads as efficiency is low
Inspect manual drains, pH of inter-cooler condensate for acidity and leakage
Replace V belts with flat belts and periodically adjust tension in drive belts

Section 7 : Economic Analysis of Investments for Energy Conservation

When any conservation opportunities are to be implemented, most measures do not require investments. However, it is possible that an investment, marginal or substantial, is sometimes incurred for specific energy saving opportunities. And, transferring the implementation from paper to actual practice involves making a decision - to invest or not to invest.

Usually, decisions are made regarding alternative solutions for utilisation of capital. At the outset, the decisions must not conflict with the objectives of the enterprise. These objectives can be constrained by social considerations or governmental regulations. They can be influenced partially by the owner's tastes or time required for implementation. However, the prime objective does not deviate from profit maximisation.

In order to aid the decision-makers, there are certain economic methodologies, which are followed. These are briefly discussed, although progressing beyond basic concepts would be beyond the scope of this manual.

All these methods are more or less reliable, depending on the accuracy of evaluation of the cash inflow and outflow, estimation of the discount rate (cost of capital) and prediction of the possible rate of increase of the energy price. Within these limitations, the most precise method is the Present Value Criterion, which compares the present value of all future after-tax cash inflow and outflow over a specified period of time to the present value of the cost of investment for the investment.

Although it may appear elementary, one has to recall here the fundamental rule of sunk costs, which says that in taking decisions about future investments, no role is played by past costs.

For example, when a new line of products is considered in a factory, the original book value of the existing old machinery already installed as irrelevant from the point of view of future cost evaluation. What is relevant is the present book value of the equipment, in the case that the old machinery can be sold or partially used to substitute the purchase of the new machinery. If the old machinery cannot be sold or used in the new production it is a "sunk cost" and has no relevance to the investment decision concerning the new machinery.

7.1 Present Value Criterion

The net present value (NPV) is defined as the difference between present worth of savings and cost of investment. The investment should be made if NPV is positive, and should be discarded if NPV is negative.

The present value method converts the money time series corresponding to the savings to an equivalent single amount at the date (year 0) when the decision to invest is to be taken. The present value criterion then compares this equivalent amount to the capital to be invested.

$$NPV = p \times \frac{1}{(1 + r)^n}$$

Where p = future payments and income

r = pre-determined discount rate

n = number of years for which NPV is calculated

NPV indicates the return that the management can expect from the project at various discount rates. It can also be used to compare various projects with similar discount rates and risks, as well as compare them against a benchmark rate.

Internal Rate of Return (IRR) is the threshold rate at which the NPV is zero. It is the rate of return received for the project considering payments and income at regular intervals. This is commonly used for analysing investments in projects. A project is considered viable, if its IRR is greater than the interest rate offered by financial institutions for investing the capital with them that would be otherwise invested in the project.

7.2 Average Rate of Return Criterion

The average rate of return on investment criterion is not so precise as the present value criterion but it can provide a preliminary guide to investment decisions provided that the projected future annual cash savings can be assumed to remain constant.

For example, suppose the installation of a heat recovery device is considered. The heat recovery system installation costs Rs.10,00,000 and will last five years.

The law permits a 20% annual linear depreciation factor. The new machine is expected to save Rs.3,00,000 in fuel costs annually.

Return on Investment (ROI)

The returns may be on the investment made or on a particular project or of the organisation as a whole.

Return on Investment (ROI) : Profit/Capital Employed

ROI is a combination of two ratios i.e., Profitability Ratio and Capital Turnover Ratio

Profitability ratio indicates the profitability of the organisation/investment/project while Capital Turnover Ratio indicates the efficiency with which the assets / investment are being employed. Greater the two ratios, higher will be the return on investment.

Generally the management analyses Profitability Ratios to take decisions pertaining to pricing policies, costs etc., while the Capital Turnover Ratio is analysed to take investment decisions.

The expected Return on Investment is generally the benchmark for investment decisions.

7.3 Pay-Back Period Criterion

The Pay-back Period Criterion evaluates the time required to recover an initial investment via an annual net cash flow. It is defined as the investment cost divided by the cash flow. In the previous example of the heat recovery systems, the pay-back time in years is equal to 3.3 years.

Similar to the return on investment method, the pay-back criterion does not take into consideration the discount rate, the change in energy prices, nor the lifetime of the investment project. It has one advantage over ROI in that a precise indication of the annual benefit, namely the cash flow, is used instead of profits. However, both suffer from the difficult in justifying the threshold value beyond which no project should be considered.

In practice, investment projects with a pay-back period of three years or less almost always have a positive net present value. Thus the pay-back period is often used as a "filter", calculating NPV when the payback period is over three years and accepting the project when it is less.

7.4 Break-Even Parameters of Net Present Value

An important part of investment analysis, not to be confused with the pay-back period, is the calculation of the threshold value of a critical parameter of the net present value (NPV).

The threshold, or break-even value, is the value of a NPV parameter for NPV equal to zero. Any value beyond the break-even value will cause NPV to become positive and the investment acceptable.

Typical parameters studied in this manner include:

- The price of the service;
- The utilisation of the capacity of the investment;
- Various items of the cost of the project;
- The energy price increase, and
- Occasionally, the duration of the project.

When the latter is used as a parameter, the break-even time (in years) is a "true" pay-back period, where the discounted benefits begin to exceed the discounted costs.

Section 8: Energy Audit Approach and Methodology

8.1 Preliminary Energy Audit (PEA)

PEA is a preliminary data gathering and analysis effort in two parts: (a) the energy management audit, wherein the auditor acquaints himself with investment decisions and criteria referencing energy conservation projects and (b) the technical energy audit using available data.

The energy auditor relies on his experience to gather all relevant written, oral or visual information that can lead to a quick analysis of the existing energy situation. It focuses on the identification of obvious sources of possible improvement in energy use, such as missing insulation, steam and compressed air leaks, inoperative instrumentation and superfluous operation. The typical output of a PEA is a set of recommendations for immediate low-cost actions and, usually, a recommendation for a detailed energy audit.

8.2 Detailed Energy Audit (DEA)

This is a measured survey followed by a plant energy analysis. Sophisticated instruments, such as flow meters, psychrometers, flue gas analysers and infrared scanners are used to enable the auditor to compute efficiency and balances during typical equipment operation. The tests performed and instruments required depend on the type of facility, the objective, scope and level of handling of the energy management programme. The tests conducted include combustion efficiency tests, measurement of temperature and airflow of major fuel-using equipment, determination of power factor degradation caused by various pieces of electrical equipment and testing of process systems for operation within specification.

After obtaining the results, the auditor validates them using preliminary computation and existing support materials such as tables and charts. Then, he builds energy and mass balances, first for each major piece of equipment tested, and then, for the plant as a whole. From such balances, he can determine the energy efficiency of each equipment and scope for possible improvement in efficiency, with costs and benefits of selected options for each opportunity. In some cases, he is unable to recommend a specific investment because of its magnitude or the associated risk. In such a case, he may recommend specific feasibility studies such as boiler replacement, furnace modification, steam system replacement and process changes. The detailed report presents the auditor's recommendations, with costs, benefits and implementation aspects.

8.3 Steps in Energy Audit Programme

In an Energy Audit, detailed data are collected and analysed. Although sophisticated instruments are used, energy auditing is not an exact science. The auditor must use his knowledge and judgement to collect and interpret data suitably. The various steps in an energy audit programme are given below:

Step 1. Review energy management programme to date

The programmes are customarily reviewed with senior corporate staff. The auditor can decide what changes may be needed in the scope of the proposed detailed energy audit. If there is no formal programme, the auditor will try to understand why.

Step 2. Conduct preliminary energy audit

The preliminary energy audit (PEA) should be conducted after the review. The PEA consists essentially of gathering and analysing data. It uses available data only, without the use of sophisticated instruments. The results of the PEA depend on the ability and experience of the auditor. The output of the PEA is normally:

- *Development of energy consumption / cost data base for a facility*
- *Objective evaluation of plant condition*
- *Identification of major energy-consuming systems*
- *Understanding of company policies for energy-related projects*
- *Action plan for future energy auditing work*

The PEA generally has six steps.

1. Organise resources

- *Manpower / time frame*
- *Instrumentation*

2. Identify data requirements

- *Data forms*

3. Collect data
a. Conduct informal interviews

- *Senior Management*
- *Energy manager/co-ordinator*
- *Plant engineer*
- *Operations and production management and personnel*

- *Administrative personnel*
- *Financial manager*

Conduct plant walkthrough/visual inspection

- *Material / energy flow through plant*
- *Major functional departments*
- *Any installed instrumentation, including utility meters*
- *Energy report procedures*
- *Production and operational reporting procedures*
- *Conservation opportunities*

4. Analyse data

a. Develop database

- *Historical data for all energy suppliers*
- *Time frame basis*
- *Other related data*
- *Process flow sheets*
- *Energy - consuming equipment inventory*

b. Evaluate data

- *Energy use - consumption, cost, and schedules*
- *Energy consumption indices*
- *Plant operations*
- *Energy saving potential*
- *Plant energy management programme*

5. Develop action plan

- *Conservation opportunities for immediate implementation*
- *Projects for further study*
- *Resources for detailed energy audit*
  - *systems for test*
  - *instrumentation - portable and fixed*
  - *manpower requirements*
  - *time frame*
- *Refinement of corporate energy management programme*

6. Implementation

- *Implement identified low cost/no cost projects*
- *Perform Detailed Audit*

Step 3. Develop action plan, including detailed energy audit

On the basis of the review and the PEA, the energy auditor should develop an action plan, including a Detailed Energy Audit (DEA), considering:

- *Management of energy-related matters*
- *Monitoring and reporting considerations*
- *Relationships with manufacturers' representatives*
- *Availability of resources for implementing the action*

Step 4. **Select scope of detailed energy audit**

The next step is to determine the scope of DEA, in order to finalise resources requirement in the following areas:

- *Manpower: Manpower required for the DEA should be selected, on the basis of the review of the PEA, from internal or external sources.*
- *Instrumentation: The DEA provides the basis for the quantitative analysis of the energy performance of the facility. To compile the operating data necessary to make this quantitative assessment, a variety of fixed and portable instrumentation is used.*
- *Testing procedures: There are standard testing procedures for evaluating equipment performance, which the auditor may use as guidelines. For example, BIS 8753 provides methods for calculating the combustion efficiency.*
- *Cost for conducting the DEA: This depends on the time required to complete the DEA, in other words, the size of the plant and the report preparation time. The use of sophisticated instrumentation and overheads also add on to the cost of the DEA.*

Step 5. Complete preparatory work

All instruments should be calibrated, serviced and/or repaired, additional instruments purchased and test measuring positions and connections completed. The auditor should make sure that the time selected for the audit does not conflict with the operation of the equipment to be tested or the plant in general. The testing date should also be representative of normal plant operation.

Step 6. Carry out detailed energy audit field work

The energy auditor can now conduct the fieldwork for the DEA, which comprises two main tasks:

The first task is to gather data to evaluate all energy aspects using the PEA as a starting point, expanding on it, to fill gaps and learn more about the plant operation.

The auditor usually interviews selected personnel, examines records, observes operations, monitors and checks conditions. This may involve repeated data collection and review.

The most important part of an energy audit consists of the preparation of energy and material balances, first for individual equipment operations and then, for the entire plant. Without such data, it is rarely possible to carry out quantitative analyses to identify potential energy savings. Instruments play a vital role in measuring, indicating and controlling process parameters to achieve energy efficiency.

The second task is to perform tests on selected equipment to evaluate its efficiency.

Step 7. Evaluate collected data

Based on the raw data generated, efficiency of various equipment is evaluated. This involves detailed calculation, using computers and at times, specially designed software.

Step 8. Identify conservation opportunities

The results of the evaluation can be used to identify the energy conservation opportunities:

- *Better operation and maintenance by low-cost housekeeping measures*
- *Recovery of waste energy*
- *Improvement in equipment efficiency*
- *Installation of advanced control systems*
- *Change of technology*

These low cost opportunities require little or no major capital investment and have immediate returns on investment. On a simple payback basis, they have paybacks of less than a year.

Capital-intensive measures require large investments. Simple payback periods are usually more than a year. The auditor should use payback period as a guideline, while making his list of recommendations. He should also keep in focus, the attitude of the management towards capital-intensive projects.

Step 9. Develop action plan of implementation

The auditor will probably not have the authority to implement the measures identified, especially if capital requirements are large. Instead, he will complete a report, which will present his findings, with a concrete and time-bound action plan.

It should usually be possible to implement some O&M measures immediately. However, capital intensive measures may require feasibility studies before a decision can be made to implement them.

An action plan often includes a recommendation for self-financing. In a self-financing programme, O&M changes are implemented and the resulting cost benefits are invested directly in lower-cost capital-intensive measures to bring in more savings. Eventually, these savings are used to pay for the most capital-intensive measures.

Step 10. Continue to monitor energy use

Energy efficiency in a company cannot begin and end with the DEA. To sustain its energy efficiency, a company must continue to monitor its energy use.

The DEA report should recommend improvements to the existing monitoring and reporting procedures for energy use. Very few companies, if any, have an adequate system of monitoring procedures. Without such a system, it is hard to spot changes in consumption that result from increase or decrease in efficiency. Possible improvements that can be made to monitoring and reporting procedures include:

- *Upgrading of instrumentation*
- *Development of energy consumption indices*
- *Development of energy models*

Step 11. Refine overall energy management programme

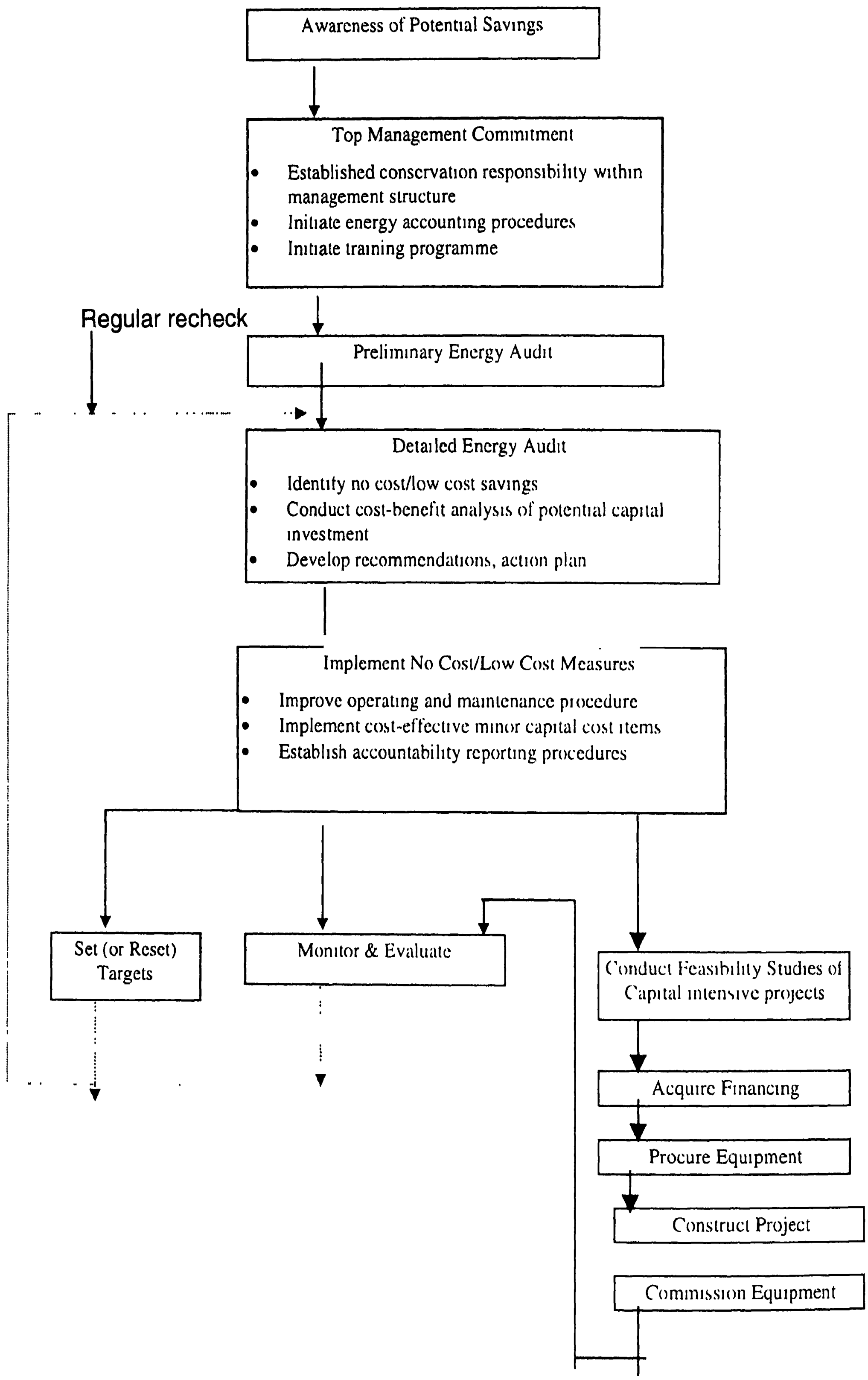
The major recommendations of the DEA should be refinements to the overall corporate energy management programme. Since energy affects so many aspects of operations, improvements in energy use cannot take place without commitment at the highest levels of management and a proper organisational framework. The management's perception of the state of energy use will determine the success of any energy management programme. Recommendations may include:

- *Appointing personnel to be responsible for energy*
- *Formally structuring a corporate energy management programme*
- *Training staff and employees in energy awareness*

In its efforts to maintain energy consumption within levels consistent with technological developments, the management may carry out regular energy audits to review the results of the improvement measures.

8.4 Energy Management Practice

The energy management process in totality can be represented as below:



8.5 The Approach to Energy Management

The commitment of top management should be clearly demonstrated in policies and directives, with company decisions to control costs being clearly defined. Active participation in energy related activities by senior management is a vital step in this approach. Chart A presents this concept schematically. Practising energy management includes mandatory functions such as:

- *Identification of possibilities for further improvement*
- *Evaluation of these opportunities to prioritise them*
- *Implementation of conservation measures*
- *Continuous monitoring to sustain and further improve upon these measures*

8.6 Preliminary Analysis

In order to develop an energy management programme, it is necessary that the scope, extent of detail and the management cost and time expended should have some relation to the potential benefits of the programme. The cost incurred should not be more than the value of energy saved. The preliminary analysis should include with a preliminary analysis of parameters such as:

- *Consumption of various forms of energy*
- *Energy cost as percentage of production cost*
- *Major energy intensive equipment*
- *Potential savings and comparison with current profit*
- *Cost of additional metering possibly required to introduce the programme*
- *Efforts within existing framework to monitor energy consumption in different departments.*

Such a broad evaluation would give a perspective of the management time and cost value in relation to potential returns.

8.7 Energy Committee

Within the company, and particularly for larger industries, an Energy Committee would play a vital role of co-ordination between various departments. This may, for example, include senior managers, the Accountant and the Chief Engineer. Since accountability and authority go hand in hand, the Chairman should be a senior functionary, with authority to ensure that all resources are made available for necessary actions.

The Committee will be responsible for:

- *Developing the energy policy*
- *Managing the monitoring system*
- *Concurring upon and reviewing standards and targets*
- *Examining energy saving schemes*
- *Ensuring project implementation*
- *Any other matters relating to energy*

8.8 Energy Manager

A full-time energy manager may be appointed to implement the energy management programme, directly accountable to the energy committee. This would also be evidence of the management concern for and commitment to energy conservation. The energy manager should be an internal appointee, to ensure good practical knowledge of all aspects of operations, both technical and administrative.

Responsibility for Results

In general, organisation structures in the industry are based on three levels of authority with corresponding responsibilities towards efficiency of energy use.

Level 1: *Senior Management with responsibility for energy efficiency in the entire organisation, in relation to other resources, and in production of particular products.*

Level 2: *Middle Management with similar responsibilities, but limited to specific areas of the manufacturing process or divisions of the organisation.*

Level 3: *Process Operators, Foremen and Supervisors with responsibility for maintaining efficiency in a particular item of plant or part of a process.*

At all levels, regular reports on actual usage compared against norms and targets will be equired in order to learn and correct deviations. The energy manager would provide these reports, analyse data, develop standards of performance and derive information for setting appropriate targets. He would also be responsible for installation and operation of metering systems and the training of staff for the collection and analysis of data.

8.9 Energy Management Process/Strategy

There are four distinct steps to the energy management process:

- *Defining energy accounting centres*

- *Measurement*
- *Analysis & Monitoring*
- *Targeting*

Energy Accounting Centres (EAC)

Along the energy flow paths of the plant, a series of energy accounting centres can provide the breakdown of energy input and output, for monitoring and achieving set targets. An EAC might comprise an individual equipment, a section or even a whole building. Each centre must have an individual responsible for both operational achievement and energy conservation, in order that his attention is focussed on the close relationship between the two aspects. He should have available pertinent information, on which to base judgements, decisions and actions to bring about improvements. Each EAC requires meters to measure the energy consumed over a period, and a means of measuring the production (or other specific variable) over the same period. As far as possible, EACs should correspond with the existing cost control centres.

Measurement

In order to be managed effectively, any resource must be measured accurately, to provide information to base decisions. Energy management depends on collection of relevant data, to judge current performance and plan for future improvements.

Analysis & Monitoring

Energy consumption and cost data can be collected and effectively used to analyse and evaluate performance. This involves regularly comparison of actual levels of consumption with a theoretical consumption defined by a set of internally based standards. These standards could be derived from a knowledge of the organisation's own capability, and then possibly further checked by reference to external norms. Difference between actual consumption and the corresponding standards will reveal either improvements in energy efficiency or a fall-off in performance levels. The information gathered, thus provides quantified evidence of the success of implementation, or will indicate any failures, in order that remedial measures can be undertaken.

The analysis should be a continuous process, and each line manager or plant operator must receive the energy throughput data regularly - on a weekly/ monthly basis - and promptly, so that deviations from standards can be quickly detected and corrected. In turn, line managers themselves must ensure that they respond rapidly

to the information they receive. Well-designed reporting forms, expressed in readily understood terms, will be very helpful. Management information systems must ensure that the appropriate data and deviations reach the highest levels of authority. Just by the introduction of a monitoring system alone, many organisations have found that they could cut their energy consumption by up to ten percent.

Targeting

Once the energy management programme has identified and prioritised on the implementation of various measures, targets can be set for the implementation of change and the achievement of the predicted energy cost savings. The choice of targets will take account of current standards and the time frame for implementing measures. A organisation may wish to set a range of targets, taking note of the scope for improvement, the resources allowed by management to effect the improvement and the need to match accountability to the energy-accountable centres.

There are two principal methods of target setting. This first is the `top down' approach, a broad based generalised technique, which does not draw on a detailed analysis of the circumstances of the organisation, but may be based on experience in the sector as a whole.

The second `bottom up' method is based on a close knowledge of the energy requirements of different parts of an organisation. Both have their merits and can be chosen, depending on the efficacy in the given circumstances. Most organisations prefer the `bottom up' approach since it is, by its very nature, more closely tailored to there needs and hence more effective.

Correctly set targets have a strong motivational effect on the workforce. But it is important to avoid either impossible or too easy targets, since these can provide counter productive.

8.10 Importance of Human Element

Means of Getting Good Co-operation from Personnel

a. Education

A well-designed familiarisation programme should convince employees of the need for good standards of housekeeping and energy awareness. They should appreciate that it is in their best interests to avoid unnecessary and excessive use of energy. Energy savings add directly to profit. However, it is important to

emphasise that sacrifices are not being sought, nor are the employees expected to work in less than satisfactory conditions. Early results are unlikely to be sustained indefinitely. People do tend to slip back into former habits, but the right climate can be established for introducing more complex and lasting measures gradually.

b. Awareness and information sharing

In most plants, employees have little or no idea of the amount of energy consumed within their plant, their section and even the equipment operated by them. In such a situation, what is required is awareness - which can be possible only by information, in the form of comparisons of historical trends, goals for overall energy use, energy intensity, in physical and monetary terms; checklists for each manufacturing operation outlining routine housekeeping measures, audio-visual presentations and literature.

Information must be presented in a manner that facilitates comprehension. If the information is too technical, theoretical, sketchy or dull, it is likely to be ignored or not understood. Terminology should be familiar to the daily life of the employees. For example, a sign saying, " stop steam leaks" will not be as effective as a sign saying " A quarter inch diameter steam leak costs Rs. 30,000/- per month".

Training is also an important means of both informing and involving people at all levels in an energy management programme. For operating personnel, training is required in practicalities of energy saving. This could be integrated into the organisation's other training programmes.

c. Motivation

Motivation is based on involvement, commitment and a sense of personal accountability. Top management must visibly demonstrate their attitude, originate the programme, generate and maintain the momentum.

Operators and maintenance staff should be involved actively, as they are ultimately responsible for execution. They are often in a better position to recommend areas for improvement. The most effective way of involving them is by simply going out and talking to them regarding goals, achievements, problems and progress or lack of progress.

Supervisors and middle level management should be involved by being assigned responsibilities for implementing and monitoring activities and submitting performance reports to top management, and by getting them to interact and communicate with operators and maintenance stand on progress and problems.

If possible, energy management activities should be made a part of each supervisor's performance or job standard.

d. Publicity

Publicity and promotion are essential to publicise the benefits to the company and the workforce. Some commonly used means could be:

1. Articles or implemented ideas in company or plant paper.
2. Obtain local newspaper interest and coverage.
3. Posters and pamphlets
4. Letterheads with energy conservation messages and ideas
5. Plant-wide, high-visibility vehicles or equipment to carry signboards
6. Monthly posting of results for the plant and department
7. Direct interactions of plant energy manager and personnel.
8. Quarterly site reviews and walk-through of unit.
9. An agenda item on energy conservation included at staff meetings.
10. Material provided to first-line supervisors for employee discussion periods.
11. Quarterly meetings held in the plant for all unit representatives
12. An Energy Awareness Day is set aside in the plant twice a year
13. Company energy logo developed and adopted.

8.11 Key Tasks of Energy Management

Energy Data Collection and Analysis

- *Maintain records of all energy consumption in the plant*
- *Check the reading of all meters and sub-meters on a regular basis.*
- *Specify additional meters required to provide additional monitoring capability.*
- *Develop indices for specific energy consumption relative to production and maintain these indices on a monthly basis for all major production areas.*
- *Set performance standards for efficient operation of machinery and facilities.*

Energy Purchasing Supervision

- *Review utility and fuel bills; ensure proper and optimum tariff application*
- *Investigate and recommend fuel-switching opportunities*
- *Develop contingency plans in the event of supply interruptions or shortages.*
- *Work with individual departments to prepare annual energy cost budgets.*

Energy Conservation Project Evaluation

- *Develop ideas, working with in-house staff, vendors and consultants*
- *Analyse economics to permit management evaluation of projects.*
- *Obtain management commitment of funds to implement projects.*
- *Re-evaluate projects in tune with growth of company*

Energy Project Implementation

- *Initiate equipment maintenance programmes for energy saving*
- *Supervise the implementation of conservation projects, including specification, requests for quotation, evaluation of offers, ordering of materials, construction/installation, training, start-up and final acceptance.*

Communications and Public Relations

- *Prepare reports to management, summarising costs and consumption*
- *Effectively communicate with all production and support departments*
- *Develop an awareness programme to encourage active participation*
- *Develop training programmes to upgrade knowledge and skills*
- *Publicise company commitment to energy conservation*

Checklist for Top Management

a. Inform line supervisors of:

- *Economic reasons to conserve energy.*
- *Responsibility for implementing actions in areas of accountability.*

b. Establish an energy committee consisting of:

- *Representatives from each department in the plant*
- *A co-ordinator appointed by and reporting to management.*

c. Provide committee with guidelines as to what is expected

- *Develop uniform record keeping, reporting and energy accounting.*
- *Research and develop ideas on ways to save energy.*
- *Communicate these ideas and suggestions.*
- *Suggest tough, but achievable, goals for energy saving.*
- *Develop ideas for enlisting employee support and participation.*

d. Set goals in energy saving, revising it based on savings potential

e. Employ external assistance in making recommendations.

f. Emphasise management's focus on conservation activities.

Duties and Responsibilities of Energy Manager/Co-Ordinator

- *Generate interest in conservation and sustain it with new ideas and activities.*
- *Summarise purchases, stocks and consumption, review and report utilisation.*
- *Focus of departmental records of use, ensuring uniformity and consistency.*
- *Co-ordinate efforts of energy users and set challenging but realistic targets*
- *Advise on techniques and source guidance on specialised subjects.*
- *Identify areas that require detailed study and prioritise them.*
- *Maintain records of all in-depth studies and to review progress.*
- *Provide basic handbook of good energy practice for operations.*
- *Advise purchasing, planning, production and other functions*
- *Ensure that health and safety are not adversely affected.*
- *Liase within industry to exchange ideas, protecting confidential data*
- *Contact research organisations, manufacturers and professional bodies*
- *Remain up-to-date on national energy matters and advise senior management.*

8.12 Instrumentation for an Energy Audit

Thermal related measurements:

The most common parameter measured is temperature. All evaluations of the heat contents of a stream or the energy consumption of a process depend on the temperature at each point of the stream or in the process. The instruments commonly used for measuring temperature are:

- *Mercury/ Bimetallic thermometer*
- *Thermocouple and indicator*
- *Thermograph*
- *Data logger*
- *Pyrometer*
- *Hygrometer*

Mechanical related measurements:

Flow measuring instruments:

- *Vane anemometer*
- *Pitot tube*
- *Air flow meter*
- *Orifice meter*
- *Venturi meter*
- *Ultrasonic flow meter*

Pressure measuring instruments:
Ultrasonic Leak Detectors
Speed measuring instruments:

- *Tachometers (Contact and Non-Contact Type)*
- *Stroboscope*

Steam trap-testing instruments:

- *Industrial stethoscope*
- *Electronic trap tester*

Chemical related measurements

- *Fyrite kit (percentage CO_2/ O_2 in the flue gas)*
- *Oxyliser (% O_2, CO_2, flue gas temperature and combustion efficiency)*
- *Flue gas analyser (%O_2,CO_2,flue gas temperature and combustion efficiency)*
- *Dragger (CO)*

Electrical related measurements:

- *Ammeter and Voltmeter*
- *Power factor meter*
- *Power analyser (A, V, pf, kW, kVA, Hz)*
- *Current recorder*
- *Multi-meter*

Lighting related measurements:

- *Lux meter*

Appendices

Alloying Element

Any metallic element added during the making of steel for the purpose of increasing corrosion resistance, hardness, or strength. The metals used most commonly as alloying elements in stainless steel include chromium, nickel, and molybdenum.

Alloy Steel

An iron-based mixture is considered to be an alloy steel when manganese is greater than 1.65%, silicon over 0.5%, copper above 0.6%, or other minimum quantities of alloying elements such as chromium, nickel, molybdenum, or tungsten are present. An enormous variety of distinct properties can be created for the steel by substituting these elements in the recipe.

Alloy Surcharge

The addition to the producer's selling price included in order to offset raw material cost increases caused by higher alloy prices.

Annealing

A heat or thermal treatment process by which a previously cold-rolled steel coil is made more suitable for forming and bending. The steel sheet is heated to a designated temperature for a sufficient amount of time and then cooled.
The bonds between the grains of the metal are stretched when a coil is cold rolled, leaving the steel brittle and breakable. Annealing "recrystallises" the grain structure of steel by allowing for new bonds to be formed at the high temperature.

Argon-Oxygen Decarburisation (AOD)

A process for further refinement of stainless steel through reduction of carbon content.

The amount of carbon in stainless steel must be lower than that in carbon steel or lower alloy steel (i.e., steel with alloying element content below 5%). While electric arc furnaces (EAF) are the conventional means of melting and refining stainless steel, AOD is an economical supplement, as operating time is shorter and temperatures are lower than in EAF steelmaking. Additionally, using AOD for refining stainless steel increases the availability of the EAF for melting purposes.

Molten, unrefined steel is transferred from the EAF into a separate vessel. A mixture of argon and oxygen is blown from the bottom of the vessel through the melted steel. Cleaning agents are added to the vessel along with these gases to eliminate impurities, while the oxygen combines with carbon in the unrefined steel to reduce the carbon level. The presence of argon enhances the affinity of carbon for oxygen and thus facilitates the removal of carbon.

Attrition

A natural reduction in work force as a result of resignations, retirements, or death.

Most unionized companies cannot unilaterally reduce their employment levels to cut costs, so management must rely on attrition to provide openings that they, in turn, do not fill. Because the median ages of work forces at the integrated mills may be more than 50, an increasing number of retirements may provide these companies with added flexibility to improve their competitiveness.

Austenitic

The largest category of stainless steel, accounting for about 70% of all production. The austenitic class offers the most resistance to corrosion in the stainless group, owing to its substantial nickel content and higher levels of chromium. Austenitic stainless steels are hardened and strengthened through cold working (changing the structure and shape of steel by applying stress at low temperature) instead of by heat treatment. Ductility (ability to change shape without fracture) is exceptional for the austenitic stainless steels. Excellent weldability and superior performance in very low-temperature services are additional features of this class. Applications include cooking utensils, food processing equipment, exterior architecture, equipment for the chemical industry, truck trailers, and kitchen sinks. The two most common grades are type 304 (the most widely specified stainless steel, providing corrosion resistance in numerous standard services) and type 316 (similar to 304 with molybdenum added, to increase opposition to various forms of deterioration).

Auto Stamping Plant

A facility that presses a steel blank into the desired form of a car door or hood, for example, with a powerful die (pattern). The steel used must be ductile (malleable) enough to bend into shape without breaking.

Basic Oxygen Furnace (BOF)

A pear-shaped furnace, lined with refractory bricks, that refines molten iron from he blast furnace and scrap into steel. Up to 30% of the charge into the BOF can be scrap, with hot metal accounting for the rest.

BOFs, which can refine a heat (batch) of steel in less than 45 minutes, replaced open-hearth furnaces in the 1950s; the latter required five to six hours to process the metal. The BOF's rapid operation, lower cost and ease of control give it a distinct advantage over previous methods.

Scrap is dumped into the furnace vessel, followed by the hot metal from the blast furnace. A lance is lowered from above, through which blows a high-pressure stream of oxygen to cause chemical reactions that separate impurities as fumes or slag. Once refined, the liquid steel and slag are poured into separate containers.

Bars

Long steel products that are rolled from billets. Merchant bar and reinforcing bar (rebar) are two common categories of bars, where merchants include rounds, flats, angles, squares, and channels that are used by fabricators to manufacture a wide variety of products such as furniture, stair railings, and farm equipment. Rebar is used to strengthen concrete in highways, bridges and buildings.

Billet

A semi-finished steel form that is used for "long" products: bars, channels or other structural shapes. A billet is different from a slab because of its outer dimensions; billets are normally two to seven inches square, while slabs are 30-80 inches wide and 2-10 inches thick. Both shapes are generally continually cast, but they may differ greatly in their chemistry.

Black Plate

Cold-reduced sheet steel, 12-32 inches wide, that serves as the substrate (raw material) to be coated in the tin mill.

Blast Furnace

A towering cylinder lined with heat-resistant (refractory) bricks, used by integrated steel mills to smelt iron from its ore. Its name comes from the "blast" of hot air and gases forced up through the iron ore, coke and limestone that load the furnace.

Bloom

A semi-finished steel form whose rectangular cross-section is more than eight inches. This large cast steel shape is broken down in the mill to produce the familiar I-beams, H-beams and sheet piling. Blooms are also part of the high-quality bar manufacturing process: Reduction of a bloom to a much smaller cross-section can improve the quality of the metal.

Briquettes

Small lumps are formed by pressing material together. Hot Iron Briquetting (HBI) is a concentrated iron ore substitute for scrap for use in electric furnaces.

Capacity

Normal ability to produce steel in a given time period. This rating should include maintenance requirements, but because such service is scheduled to match the needs of the machinery (not those of the calendar), a mill might run at more than 100% of capacity one month and then fall well below rated capacity as maintenance is performed.

> **Engineered Capacity** The theoretical volume of a mill, given its constraints of raw material supply and normal working speed.
>
> **"True" Capacity** Volume at full utilization, allowing for the maintenance of equipment and reflecting current material constraints. (Bottlenecks of supply and distribution can change over time and capacity will expand or reduce.)

Carbon Steel

Steel that has properties made up mostly of the element carbon and which relies on the carbon content for structure. Most of the steel produced in the world is carbon steel.

Charge

The act of loading material into a vessel. For example, iron ore, coke and limestone are

charged into a Blast Furnace; a Basic Oxygen Furnace is charged with scrap and hot metal.

Coke

The basic fuel consumed in blast furnaces in the smelting of iron. Coke is a processed form of coal. About 1,000 pounds of coke are needed to process a ton of pig iron, an amount which represents more than 50% of an integrated steel mill's total energy use.

Metallurgical coal burns sporadically and reduces into a sticky mass. Processed coke, however, burns steadily inside and out, and is not crushed by the weight of the iron ore in the blast furnace.

Inside the narrow confines of the coke oven, coal is heated without oxygen for 18 hours to drive off gases and impurities.

Cold-Rolled Strip (Sheet)

Sheet steel that has been pickled and run through a cold-reduction mill. Strip has a final product width of approximately 12 inches, while sheet may be more than 80 inches wide. Cold-rolled sheet is considerably thinner and stronger than hot-rolled sheet, so it will sell for a premium.

Cold Working (Rolling)

Changes in the structure and shape of steel achieved through rolling, hammering, or stretching the steel at a low temperature (often room temperature).

To create a permanent increase in the hardness and strength of the steel. The application of forces to the steel causes changes in the composition that enhance certain properties. In order for these improvements to be sustained, the temperature must be below a certain range, because the structural changes are eliminated by higher temperatures.

Consumption

Measures the physical use of steel by end users. Steel consumption estimates, unlike steel demand figures, account for changes in inventories.

Continuous Casting

A method of pouring steel directly from the furnace into a billet, bloom, or slab directly from its molten form.

Continuous casting avoids the need for large, expensive mills for rolling ingots into slabs. Continuous cast slabs also solidify in a few minutes versus several hours for an ingot. Because of this, the chemical composition and mechanical properties are more uniform.

Steel from the BOF or electric furnace is poured into a tundish (a shallow vessel that looks like a bathtub) atop the continuous caster. As steel carefully flows from the tundish down into the water-cooled copper mold of the caster, it solidifies into a ribbon of red-hot steel. At the bottom of the caster, torches cut the continuously flowing steel to form slabs or blooms.

Corrosion

The gradual degradation or alteration of steel caused by atmosphere, moisture, or other agents.

Desulphuurisation

Operation that injects a chemical mixture into a ladle full of hot metal to remove sulfur prior to its charging into the Basic Oxygen Furnace.
Sulfur enters the steel from the coke in the blast furnace smelting operation, and there is little the steelmaker can do to reduce its presence. Because excess sulfur in the steel impedes its welding and forming characteristics, the mill must add this step to the steelmaking process.

Direct Reduced Iron (DRI)

Processed iron ore that is iron-rich enough to be used as a scrap substitute in electric furnace steelmaking.

As mini-mills expand their product abilities to sheet steel, they require much higher grades of scrap to approach integrated mill quality. Enabling the mini-mills to use iron ore without the blast furnace, DRI can serve as a low residual raw material and alleviate the mini-mills' dependence on cleaner, higher-priced scrap.

The impurities in the crushed iron ore are driven off through the use of massive amounts of natural gas. While the result is 97% pure iron (compared with blast furnace hot metal, which, because it is saturated with carbon, is only 93% iron), DRI is only economically feasible in regions where natural gas is attractively priced.

Ductility

Ability of steel to undergo permanent changes in shape without fracture at room temperature.

Electric Arc Furnace (EAF)

Steelmaking furnace where scrap is generally 100% of the charge. Heat is supplied from electricity that arcs from the graphite electrodes to the metal bath. Furnaces may be either an alternating current (AC) or direct current (DC). DC units consume less energy and fewer electrodes, but they are more expensive.

Feedstock

Any raw material.

Ferritic

The second-largest class of stainless steel, constituting approximately 25% of stainless production.

Ferritic stainless steels are plain chromium steels with no significant nickel content; the lack of nickel results in lower corrosion resistance than the austenitics (chromium-nickel stainless steels). Ferritics are best suited for general and high-temperature corrosion applications rather than services requiring high strength. They are used in automotive trim and exhaust systems, interior architectural trim, and hot water tanks. Two of the most common grades are type 430 (general-purpose grade for many applications, including decorative ones) and type 409 (low-cost grade well suited to withstanding high temperatures).

Ferroalloy

A metal product commonly used as a raw material feed in steelmaking, usually containing iron and other metals, to aid various stages of the steelmaking process such as

deoxidation, desulphurisation, and adding strength. Examples: ferrochrome, ferromanganese, and ferrosilicon.

Ferrochrome

An alloy of iron and chromium with up to 72% chromium. Ferrochrome is commonly used as a raw material in the making of stainless steel.

Ferrous

Metals that consist primarily of iron.

Flat-Rolled Steel

Category of steel that includes Sheet, Strip, and Tin Plate, among others.

Flux

An iron cleaning agent. Limestone and lime react with impurities within the metallic pool to form a slag that floats to the top of the relatively heavier (and now more pure) liquid iron.

Galvanized Steel

Steel coated with a thin layer of zinc to provide corrosion resistance in underbody auto parts, garbage cans, storage tanks, or fencing wire. Sheet steel normally must be cold-rolled prior to the galvanizing stage.

Hardening

Process that increases the hardness of steel, i.e., the degree to which steel will resist cutting, abrasion, penetration, bending, and stretching.

The increased endurance provided by hardening makes steel suitable for additional applications.

Hardening can be achieved through various methods, including (1) heat treatment, where the properties of steel are altered by subjecting the steel to a series of temperature changes; and (2) cold working, in which changes in the structure and shape of steel are

achieved through rolling, hammering, or stretching the steel at a relatively low temperature.

Heat (of steel)

A batch of refined steel. A basic oxygen or electric furnace full of steel. One heat of steel will be used to cast several slabs, blooms or billets.

Heat Treatment

Altering the properties of steel by subjecting it to a series of temperature changes.

To increase the hardness, strength, or ductility of steel so that it is suitable for additional applications.

The steel is heated and then cooled as necessary to provide changes in the structural form that will impart the desired characteristics. The time spent at each temperature and the rates of cooling have significant impact on the effect of the treatment.

Hot Briquetted Iron (HBI)

Direct reduced iron that has been processed into briquettes. Instead of using a blast furnace, the oxygen is removed from the ore using natural gas and results in a substance that is 90%-92% iron. Because DRI may spontaneously combust during transportation, HBI is preferred when the metallic material must be stored or moved.

Hot-Strip Mill

A rolling mill of several stands of rolls that converts slabs into hot-rolled coils. The hot-strip mill squeezes slabs, which can range in thickness from 2-10 inches, depending on the type of continuous caster, between horizontal rolls with a progressively smaller space between them (while vertical rolls govern the width) to produce a coil of flat-rolled steel about a quarter-inch in thickness and a quarter mile in length.

I-Beams

Structural sections on which the flanges are tapered and are typically not as long as the flanges on wide-flange beams. The flanges are thicker at the cross sections and thinner at the toes of the flanges. They are produced with depths of 3-24 inches.

Ingot

A form of semi-finished steel. Liquid steel is teemed (poured) into molds, where it slowly solidifies. Once the steel is solid, the mold is stripped, and the 25- to 30-ton ingots are then ready for subsequent rolling or forging.

Integrated Mills

These facilities make steel by processing iron ore and other raw materials in blast furnaces. Technically, only the hot end differentiates integrated mills from mini-mills. However, the differing technological approaches to molten steel imply different scale efficiencies and, therefore, separate management styles, labor relations and product markets. Nearly all domestic integrated mills specialize in flat-rolled steel or plate.

Iron Carbide

One of several substitutes for high-quality, low-residual scrap for use in electric furnace steelmaking. Iron carbide producers use natural gas to reduce iron ore to iron carbide.

Iron Ore

Mineral containing enough iron to be a commercially viable source of the element for use in steelmaking. Except for fragments of meteorites found on Earth, iron is not a free element; instead, it is trapped in the earth's crust in its oxidized form.

Ladle Metallurgy Furnace (LMF)

An intermediate steel processing unit that further refines the chemistry and temperature of molten steel while it is still in the ladle. The ladle metallurgy step comes after the steel is melted and refined in the electric arc or basic oxygen furnace, but before the steel is sent to the continuous caster.

Mini-Mills

Normally defined as steel mills that melt scrap metal to produce commodity products. Although the mini-mills are subject to the same steel processing requirements after the caster as the integrated steel companies, they differ greatly in regard to their minimum efficient size, labor relations, product markets, and management style.

Pellets

Iron ore or limestone particles are rolled into little balls in a balling drum and hardened by heat.

Pulverized Coal Injection System (PCI)

A blast furnace enhancement to reduce an integrated mill's reliance on coke (because of environmental problems with its production). Up to 30% of the coke charged into the blast furnace can be replaced by this talcum-like coal powder, which is injected through nozzles at the bottom of the furnace.

Q-BOP

Modified Basic Oxygen Furnace in which the oxygen and other gases are blown in from the bottom, rather than from the top. While the Q-BOP stirs the metal bath more vigorously, allowing for faster processing, the design produces essentially the same steel grades as the top-blowing basic oxygen furnace. Today's state-of-the-art furnace design combines the previous technologies: 60% of the oxygen is blown from above, with the rest blown through the bottom of the vessel

Refractory Brick

Heat-resistant brick. Because its melting point is well above the operating temperatures of the process, refractory bricks line most steelmaking vessels that come in contact with molten metal, like the walls of the blast furnace, sides of the ladles, and inside of the BOF.

Residuals

The impurities in mini-mill steel as the result of the mix of metals entering the process dissolved in obsolete scrap. Residuals are key concerns regarding the mini-mills' recent entry into the flat-rolled market, where high residuals can leave sheet steel too brittle for customer use.

Reversing Mill

The stand of rolls used to reduce steel sheet or plate by passing the steel back and forth between the rolls; the gap between the rolls is reduced after each pass.

Rod

Round, thin semi-finished steel length that is rolled from a billet and coiled for further processing. Rod is commonly drawn into wire products or used to make bolts and nails. Rod trains (rolling facilities) can run as fast as 20,000 feet per minute or more than 200 miles an hour.

Secondary Steel

Steel that does not meet the original customer's specifications because of a defect in its chemistry, gauge or surface quality. Mills must search to find another customer (that can accept the lower quality) to take the off-spec steel at a discount. While secondary will not affect the reported yield, margins will suffer.

Semi-finished Steel

Steel shapes—for example, blooms, billets or slabs—that later are rolled into finished products such as beams, bars or sheet. Sendzimir Mill (Z-mill) WHAT Compact mill used for rolling cold coils of stainless steel in order to make the steel thinner, smoother, and stronger.

To control the thickness of steel better at lower capital cost, and to roll thinner sheets and strips.

Stainless steel sheet or strip passes between a matching pair of small work rolls with extremely smooth surfaces, heavily reinforced by clusters of back-up rolls. The rolls reduce the steel to the desired thickness. Service Center A catchall name for an operation that buys steel, often processes it in some way and then sells it in a slightly different form. A service center is distinguished from an end-user by the fact that, unlike an end-user, a service center sells steel, not a fabricated product. Service centers are manufacturers to the extent that they add labor to steel by providing a service.

Shearing

If the edges of sheet and strip are not controlled during reduction, they must be trimmed parallel by shears. This process may be performed by either the steel mill or steel processor to match customer needs.

Sheet Steel

Thin, flat-rolled steel. Coiled sheet steel accounts for nearly one-half of all steel shipped domestically and is created in a hot-strip mill by rolling a cast slab flat while maintaining the side dimensions. The malleable steel lengthens to several hundred feet as it is squeezed by the rolling mill. The most common differences among steel bars, strip, plate, and sheet are merely their physical dimensions of width and gauge (thickness).

Sinter

Baked particles that stick together in roughly one-inch chunks. Normally used for iron ore dust collected from the blast furnaces.

Slab

The most common type of semi-finished steel. Traditional slabs measure 10 inches thick and 30-85 inches wide (and average about 20 feet long), while the output of the recently developed "thin slab" casters is approximately two inches thick. Subsequent to casting, slabs are sent to the hot-strip mill to be rolled into coiled sheet and plate products.

Slag

The impurities in a molten pool of iron. Flux such as limestone may be added to foster the congregation of undesired elements into a slag. Because slag is lighter than iron, it will float on top of the pool, where it can be skimmed.

Steckel Mill

A reversing steel sheet reduction mill with heated coil boxes at each end. Steel sheet or plate is sent through the rolls of the reversing mill and coiled at the end of the mill, reheated in the coil box, and sent back through the Steckel stands and recoiled. By reheating the steel prior to each pass, the rolls can squeeze the steel thinner per pass and impart a better surface finish.

Steel Intensity

The amount of steel used per unit of gross domestic product. Intensity reflects the secular demand for steel, as opposed to cyclical demand. The amount of steel used in vehicles and the popularity of alternative materials affect the intensity, or how much steel is needed per unit produced. The state of the economy, however, determines the number of units.

Steel-Intensive Products

Consumer products such as automobiles and appliances that, because so much of their weight is from steel, exhibit a high demand correlation with steel.

Tandem Mill

A type of cold-rolling mill, the tandem mill imparts greater strength, a uniform and smoother surface, and reduced thickness to the steel sheet. Unlike the original single-stand mills, a tandem mill rolls steel through a series of rolls (generally three to five in a row) to achieve a desired thickness and surface quality.

Tundish

The shallow refractory-lined basin on top of the continuous caster. It receives the liquid steel from the ladle, prior to the cast, allowing the operator to precisely regulate the flow of metal into the mold.

Walking Beam Furnace

A type of continuous reheat furnace in which the billet or slab moves through distinct heating zones within the furnace: By controlling the speed through the zones, steelmakers can achieve precise rolling temperatures and consume less fuel during operation.

Yield

The ratio of the quantity of finished shipments to the total raw steel produced, adjusted for changes in inventory and any slabs that are purchased from outside. Yield has significantly improved during the past decade, primarily as the result of the industry's conversion to continually cast steel, whose yield is superior to that of traditional ingot teeming.

Concept

Electric arc furnaces are major energy guzzlers in the Secondary Iron & Steel Industry. The furnaces are used for melting of scrap and the recent trend is for melting sponge iron. The specific energy consumption for electric arc furnaces in India is around 650-700 kWh/t of metal melted. This is because these furnaces have not adopted the recent technological upgradations like ultra-high power, eccentric bottom tapping and hot heel practice, oxy-fuel burners, computerised melt controls, foamy slag practice, waste heat recovery etc. Technologies and practices such as these have enabled the world's leading companies to operate their furnaces at a specific consumption of 380-400 kWh/t.

Oxy-fuel burner is one such innovative technology, which has been prevalent in the Iron & Steel Industry. The idea behind this measure is to provide directional input of heat during the meltdown of scrap in the electric arc furnace. The heat is input by supplementing electric power with liquid/gas fuels.

The thermal distribution of heat in any a.c electric arc furnace is non-uniform. This is illustrated in Fig. 1. In an arc furnace, each arc delivers its heat to a section of the furnace in the vicinity of the arc. The three arcs repel each other by electro-magnetic force, thus creating a concentration of arc heat outside each electrode.

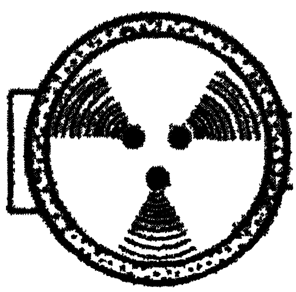


Fig. 1 : Heat Distribution In Ac Arc Furnace

This phenomenon leads to the formation of cold spots in the furnace. The meltdown becomes asymmetrical leading to slowing down of melting process and undesirable occurrences like metal splashing.

Burners are used to provide heat to the local cold spots, usually near the periphery of the bath or near the doors. These burners use liquid fuels or natural gas and oxygen is also delivered through the burner for combustion. Air is not used to prevent ingress of nitrogen and avoid unnecessary exhaust gas losses. Figures 2 & 3 illustrate the use of oxy-fuel burners on the sidewalls of a furnace.

The oxy-fuel burners can be introduced through the slag door or can be fixed to the sidewall or roof margins depending on the size and shape of the furnace and location of cold spots.

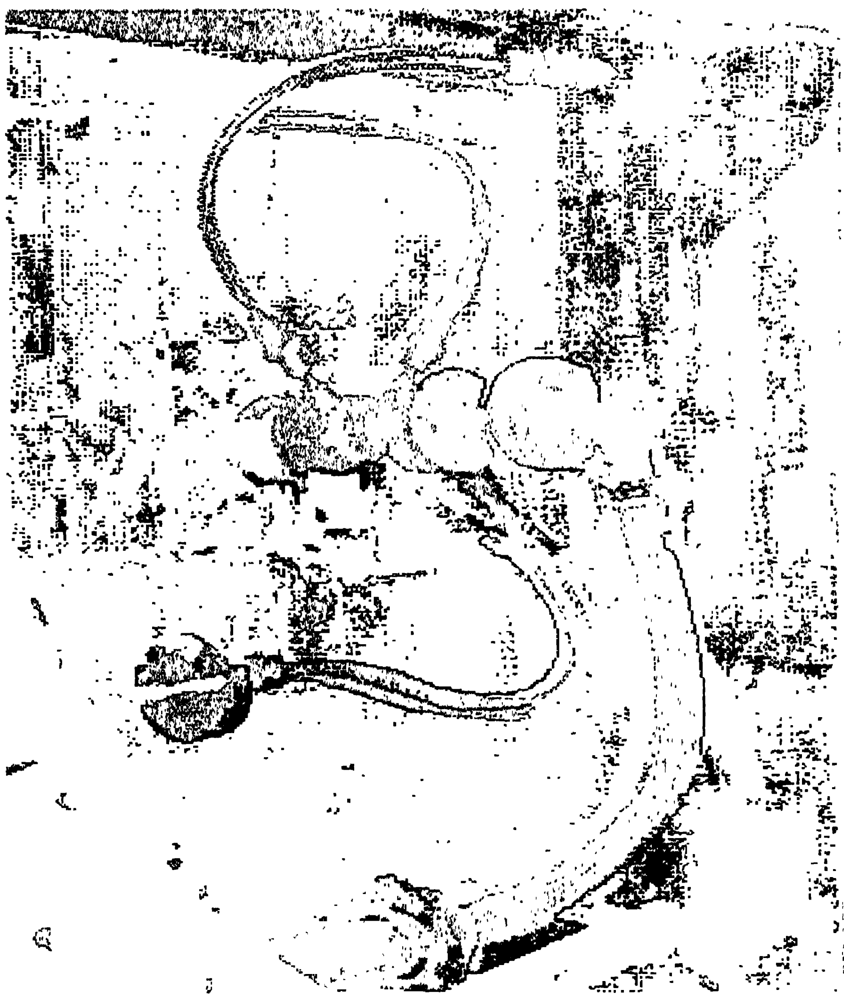


Fig 2 : External View of Oxy-Fuel Burner Installed on Sidewall

The burners provide directional, controlled heat to the cold spots. The melting and heating process in the arc furnace is speeded up and the fixed losses by way of cooling water and surface are reduced. The electric power requirement is thus reduced and replaced on a smaller scale by heat from fuels.

Application Potential

Energy conservation by oxy-fuel burners is applicable to all electric arc furnaces in the secondary Iron & Steel Industry. There are nearly 200 electric arc furnaces in the country and around 40 furnaces are of 20 t and above capacity. It is more beneficial in furnaces where there is single or multiple charging of scrap. A larger size furnace would require 3

fixed oxy-fuel sidewall burners whereas a furnace of 10-15t may make use of an oxy-fuel burner introduced through the slag or side door.

Energy savings of 5-6% of the specific power consumption in electric arc furnaces are being realised by oxy-fuel burners. This technology is not used in any of the furnace units in the country. Thus a good potential for improved energy efficiency through this measure exists in the country.

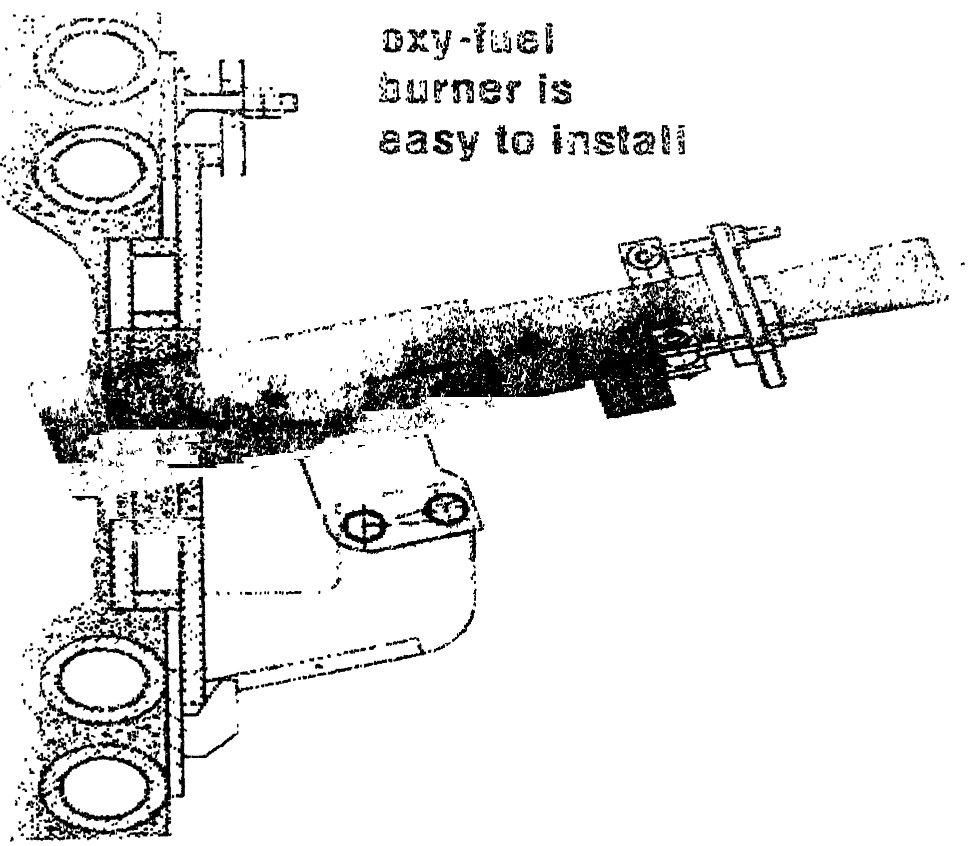


Fig.3 : Diagrammatic Representation of Oxy-Fuel Burner Mounting

Energy Saving Potential

The use of oxy-fuel burners has brought down the specific power consumption by a maximum of 40 kWh/t in electric arc furnaces. In addition to the energy savings, the other benefits are increased productivity and reduction in melting time. There is also a marginal decrease in specific electrode and refractory consumption.

The estimated investment could be Rs. 10-25 lakh, depending on the number of burners, type of fuel, local conditions in a unit etc. The payback period for oxy-fuel burners is 8-12 months even after considering operating cost of fuel and oxygen.

Existing Installations

At present, there are no Indian industries using these burners in the electric arc furnaces. It is reported that the burners have been tried at one or two arc furnaces and the experiment was not successful due to insufficient technological backup.

The arc furnace industry outside India has a large number of installations of oxy-fuel burners and it can be safely stated that it is a very common retrofit.

Appendix 3 : Emerging Trends in the Mini-Steel Industry

Some emerging trends for the mini-steel plants have been focussed on energy conservation. These are discussed in brief.

The Indian EAF industry corresponds to the 1965s or at the most 1970s in terms of technological advances. Scrap preheating was introduced in the early 80s and has since made may advances. The most significant at this juncture appears to be single power source, twin-vessel system employing 2 DC electric arc furnaces, located closely alongside and the off-gas exhaust from the preheating vessel is located as low as possible. Other noticeable developments are Shaft Furnace System and Continuous Scrap Feeding System (CONSTEEL Process). Each preheating system seems to have some room for future technological improvement, but at present, the single-power source, twin-vessel system have outpaced others in terms of heat recovery. (35-40 kWh/t compared to 28 to 33 kWh/t in case of shaft furnace and 20-25 kWh/t in case of CONSTEEL).

The production of existing EAF units and operational efficiency have been improved markedly as a number of new operating practices have been evolved as follows:

- **Raw Material Charging**

Charging practices affect both the EAF productivity and the material consumption rate. Faster melting require an optimum scrap mix for each heat. Scrap chemistries, densities and the basket loading sequence must be considered. Development of a computerised charging programme is essential for proper control. For an optimal EAF operation the recommended procedure is to charge two-thirds of the scrap in the first basket and the reminder one third in the second basket. Continuous feeding of fragmented scrap via the roof during melting limits the charging basket and reduces the power off times and heat losses caused by furnace roof opening. pneumatic injection of the lime during melting improves both de-phosphorisation and de-sulphurisation and eliminates the need to charge lime in the basket.

- **Slag Free Tapping**

Prevention of oxidising slag from entering the ladle is essential for the efficient operation of subsequent ladle refining and continuous casting. Several means are used to prevent or reduce furnace slag entering the receiving ladle, and most fall into two categories; vessel manipulation and stream interruption.

Vessel manipulation includes techniques where the furnace is quickly tilted back while the ladle is pulled away by a crane when slag is first detected in the molten stream. Some

oxidising slag tends to drain into the receiving ladle, because of the vortex formation caused by tapping. The emergence of Eccentric Bottom Tapping (EBT) has made a major contribution in achieving a slag free tapping condition. Additional benefits of EBT lie in the extension of water-cooled panels, lower temperature loss and reduced gas pick up by molten steel during tapping.

- **Submerged Inert Gas Stirring**

Attempts have been made to intensify the heat transfer within the molten bath, and between the molten bath and un-melted scrap, leading to faster melting rates. Submerged inert gas stirring has been conducted in a EAF by Union Carbide Corporation. Argon and nitrogen were injected through three placed in the furnace bottom. Besides lying on a circle of 60% of the furnace hearth diameter and being midway between the electrodes, these injection sites represent the locations of cold spots within the furnace. Improvements of 5-6% of total energy efficiency in melting, faster melting rates and greater alloy recoveries have been reported with flow rates of 0.19 Nm^3/min. The process has demonstrated a nitrogen dissolution rate of 7% below that generally encountered in a conventional steel making.

- **Continuous Melting System**

Over the years, considerable efforts have gone into the developments of an improved EAF continuous melting system. A major stride in this area has been by America's Intersteel Technology Inc., which introduced a successful technology known as Consteel. This permits operators continuously to preheat, charge and melt furnace feed stock while simultaneously refining molten steel. With this process, hot off-gases from the EAF are used as - with added fuel if economical-to preheat the scrap. Oxygen and coal are blown into the melt via submerged tuyeres to assist rapid melting. Molten steel is tapped periodically from the bottom while maintaining full power, most of the time.

If the charge is preheated with furnace off-gases to 500° C, energy requirement would drop to around 380 kWh/t, as against 470 kWh/t with 100% cold scrap practice. If the scrap preheating temperature is raised to 900°C using combined furnace off gases with 30 Nm^3/t natural gas, a sharp decline in energy requirement to 280 kWh/t could be anticipated. Noise level, fume emission and baghouse load are reduced as both the bath and arc are under an almost continuous cover of foamy slag. With an array of secondary steel making processes, the system could produce a heat every 45 - 55 min.

Japan Steel Manufacturing Co. has developed EAF with Bottom Furls Injection with combination of blowing of oxygen into the EAF. It involves injection of coal fines and other pulverised material, as well as blowing of oxygen, nitrogen and propane through submerged tuyeres, and post-combustion tuyeres.

Efficient post combustion of process gases within the furnace, and a rapid melting process through oxidation have been achieved with effective heat transfer to the scrap and the melt. If this process is operated with oil- oxygen burners, but without coal injection, it requires electrical power in the range of 410 kWh/t liquid steel. Electrical power reportedly drops to 300 kWh/t when the process is operated with coal additions of 22 -30 kg with a melting time of 48-50 minutes.

- **Future Trends**

EAF steel making capacity has witnessed a phenomenal growth during the past two decades. This can largely be attributed to its versatility, its ability to be built in different size configurations, its comparatively low capital costs and energy requirements, its enhanced production capability the abundant supply of cheap scrap, and the proliferation of mini-mills. Against this, the EAF process remains vulnerable to several adverse effects like shortage of quality scrap, rising prices of electricity and stringent environmental legislation. It also finds difficulty in producing certain grades of steel products.

The future course of the EAF process is predictable to some extent, as it is influenced by current economical and market factors. To remain competitive, it must continue to strive for higher efficiency at minimum conversion costs, consistent with the desirable quality requirements. Melt-shop operators and engineers will continue to play a crucial part in this endeavour.

- **Technical Innovations to Reduce Costs**

Cost reduction is a perennial concern. It can generally be brought about by a faster melting cycle, enhanced steel yields and furnace viability an increase in ferro-alloy yield optimised lancing, and improved project engineering and operational procedures. This would require all equipment and machinery involved to operate correctly and reliably, and every stage of steel making to perform effectively and efficiently. Properly directed technological innovations hold the key towards achieving these goals. In addition, lower costs and better quality are compatible, where materials, time and labour are wasted.

Modern EAF units are frequently complex, and present some problems in construction, operation and maintenance. There are still many examples in existing EAF units of comparatively low performance which are often related to poor organisational measures and planning and inadequate operational monitoring. Moreover, the thermal efficiency for

most EAF operations is poor, with about 30% of the potential energy being lost via the waste gases during steel making.

Continual search for innovations which could lower capital costs, consume less energy, and require less labour with the currently employed technology, and simultaneously have the capability of producing improved steel quality, remains paramount. Currently, there are many activities being carried out at various universities and research establishments. Some related to incremental improvements of the existing technology, while others call for radical innovations or new processes. Basic research has enlightened new topics like removal of copper from scrap, improving AC and DC power systems, heat transfer models in scrap preheating, nitrogen pick-up in steel, improved heat and mass transfer by gas injection, and the use of plasma extended arcs for various aspects of production. New advances in these fields would not, however, arise without heavy investment and testing, new materials, and sophisticated measurement, control and computing systems.

Much investment will be directed towards automation and modernisation of existing EAF facilities. Fast changing technologies, in related areas such as sensing techniques, instrumentation, automation, melt analysis, secondary steelmaking and continuous casting are likely to affect the future development of this technology. With advances in electronics and computer technology, optimisation of steelmaking practice with real time computer control is now possible. A key component of overall steelmaking cost reduction is the linkage of major processing stages of the steel production sequence. Major strides can be expected in the technology of continuous EAF steelmaking, which would be fully integrated with continuous casting.

By far, the greatest potential for further cost reduction in the next 5-10 years would be the application of a low cost super computer in the EAF melt-shop. This technology would allow a more efficient and yet flexible steelmaking operation by utilising the following three configurations

1. Overall master charge design to obtain the lowest cost utilisation of ferrous scrap for the melt-shop

2. Imaging system that is able to recognise a number of events during steelmaking and to give their exact time quantify them as they occur, to ensure that the necessary operations are being consistently performed.

3. Application of an artificial intelligence, expert system that has a man/machine interface that will assist steel makers to make decisions.

- **DC Arc Furnace**

EAFs conventionally use three graphite electrodes. D.C arc furnace technology is a goal to control increasing production costs. The progress in thyristor technology made it possible to replace the A.C arc furnace with single electrode D.C arc furnace.

The single electrode has made the D.C arc furnace simple in design construction and operation. The favourable impact on the D.C arc furnace operating costs is the reduced consumption of graphite electrode by 50% to 60%, electrical power by 5 - 7% and metal loss by 2 - 4%

The single graphite electrode acts as a cathode. The return path of current is through a bi-metallic water-cooled anode, placed at the bottom. There are many other advantages like less fluctuation in electric network, low noise, less maintenance.

- **DC Power Supply Requirement**

The DC power for DC EAF comprises of following main components

* High voltage switchgear
* Rectifier transformer
* Thyristor controlled converter with cooling system
* DC Reactor
* High current carrying busbars
* Bottom electrodes

- **Bottom Electrodes**

The DC EAF technology is different from AC EAF technology in that bottom electrode is used. The bottom electrode is one of the most critical components of the DC EAF.

Efficient post combustion of process gases within the furnace, and a rapid melting process through oxidation have been achieved with effective heat transfer to the scrap and the melt. If this process is operated with oil- oxygen burners, but without coal injection, it requires electrical power in the range of 410 kWh/t liquid steel. Electrical power reportedly drops to 300 kWh/t when process is operated with coal additions of 22 - 30 kg with a melting time of 48-50 minutes.

Appendix 4 : Efficient Ladle Pre-heating System

In any metal melting process it is very essential to maintain the molten metal temperature during pouring, transportation & casting. Ladles are employed to transport the liquid metal to casting facility. To avoid the drop in liquid metal temperature during transport and casting, pre heating of ladles are essential for efficient and safe operation. The other objectives of ladle preheating include avoiding thermal shock due to high temperature difference between ladle refractory & hot molten metal, driving off moisture present in the lining, preventing undue chilling of liquid metal & avoiding skull formation, to prevent solidification of molten metal in side the ladle, etc.

The primary importance of ladle preheating cycle is to supply gradually a quantity of heat to the ladle walls and distribute it uniformly through out the refractory to obtain an adequate temperature gradient to over come the heat losses during transportation and pouring.

An oil-fired burner is commonly used for ladle preheating, where oil is fired in an open atmosphere. The heating station will be either vertical or horizontal. In case of steel melting units ladle refractory lining is normally preheated to the temperature between 700-1000°C and the oil consumption vary in the range 3.5-4.5 liters per Mt.

Though ladle preheating consumes substantial energy, it is often given a lower priority. None of the heating stations use heat recovery techniques and little attention are given to fuel economy.

The study of conventional ladle preheating study reveals the following:

- The efficiency of process given by the heat stored in the refractory varies in the range 25-45%. The energy efficiency of heating a cold ladle is as low as 10%.
- Major losses are flue gas losses, which accounts majority of heat input due to non-existence of waste heat recovery units.

Thus need for energy efficient ladle preheating arises with the following objectives:

- To reduce the energy consumed in preheating
- To reduce the energy consumed in melting units by avoiding the excess superheat of the molten metal
- To increase the lining life of the ladle
- To improve the working conditions in the shop
- To achieve more uniform heating.

Appendix 4 : Efficient Ladle Pre-heating System

A substantial improvement in energy utilization can be made in ladle preheating by simple changes and in-corporation of the waste heat recovery unit.

Product Profile:

The energy efficient ladle preheating system incorporates a recuperator in the exhaust gas duct to preheat the combustion air. Furthermore the exhaust gas is used to heat the outer surface of the ladle. The advantages of this system are:

- Combustion air preheat temperatures can reach as high as 320 °C
- The outer surface can be preheated up to 190 °C
- Energy savings in the order of 8-20%
- Uniform distribution of temperature across the refractory
- Reduction in heating cycle

This system of ladle preheating has came into vogue in Germany as a result of search for energy savings. In India, there is no such type of system even though design and development of unit is not complicated. A schematic representation is shown in Fig.

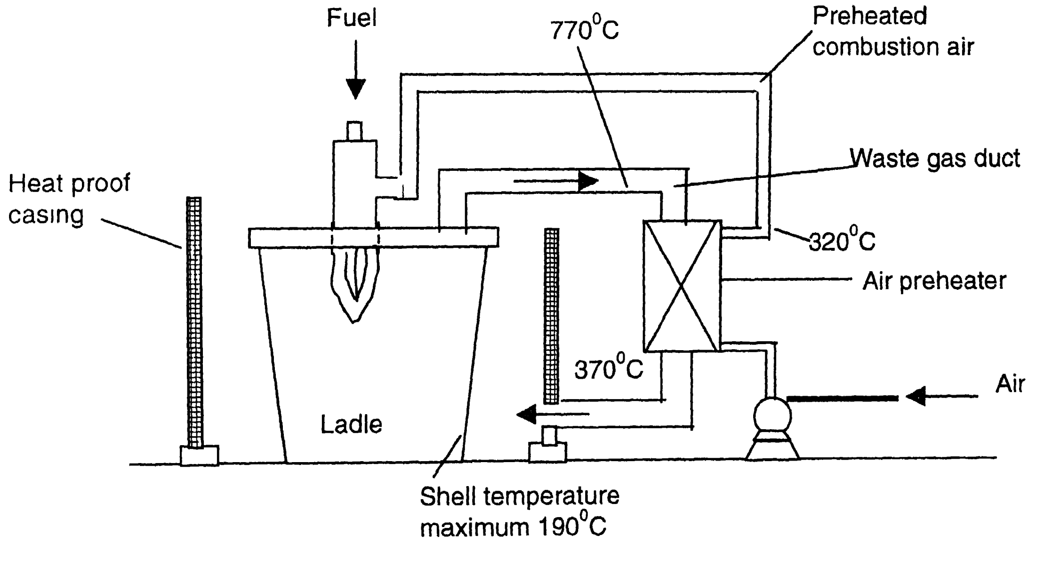


Fig.1 : Schematic Representation of Ladle Pre-heating System

Areas of Application

This system can be applied in Mini steel units (having furnace capacity above 10 Mt.) and using ladles for transport/casting/refining applications.

The installation of such units is simple and doesn't invite any technology transfers, and existing units can be easily replaced. In India, so far no manufacturer developed such packaged units.

Energy Saving Potential

Energy saving potential vary according to the industry and capacity of the ladle. In case of steel industry the energy saving potential is about 8-20%. Estimation of energy saving potential is evaluated by considering a ladle capacity of 50 Mt (Source: Energy audit of a local Iron & Steel Industry conducted by TERI).

Capacity of the ladle	: 50 Mt.
Ladle preheat temperature (hot face)	: 950-1000°C
HSD consumption rate	: 147 kg/h
Flue gas temperature	: 860°C
Proposed temperature of combustion air	: 320°C
Percentage possibility of heat recovery	:30%of heat in flue gases
Percentage savings	: 9% heat input
Savings in fuel	: 90 kL per year
Cost savings	:Rs.5.9 lakh/year
Approximate investment required	: Rs. 6.0 lakh
Payback period	: One year

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- Steam Gene[redacted] and Utilisation
- Compressed Air Systems
- Pumping Systems
- Industrial Electricity Supply Sy
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